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INTERNATIONAL APPLICATION PUBLISHED

WO 9602648A1

(51) International Patent Classification 6 :

C12N 15/31, C07K 14/285, A61K 39/102, A1
C12N 1/21, 5/10, C12Q 1/68

(43) International Publication Date: 1 February 1996 (01.02.96)

(21) International Application Number: PCT/US95/08789

(22) International Filing Date: 13 July 1995 (13.07.95)

(30) Priority Data:

| | | |
|------------|-------------------------|----|
| 08/277,231 | 19 July 1994 (19.07.94) | US |
| 08/473,750 | 7 June 1995 (07.06.95) | US |
| 08/477,326 | 7 June 1995 (07.06.95) | US |

(60) Parent Applications or Grants

(63) Related by Continuation

| | |
|----------|-------------------------|
| US | 08/277,231 (CIP) |
| Filed on | 19 July 1994 (19.07.94) |
| US | 08/473,750 (CIP) |
| Filed on | 7 June 1995 (07.06.95) |
| US | 08/477,326 (CIP) |
| Filed on | 7 June 1995 (07.06.95) |

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(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG).

Published

With international search report.

Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: LKP PILIN STRUCTURAL GENES AND OPERON OF NONTYPABLE HAEMOPHILUS INFLUENZAE

(57) Abstract

The invention relates to the isolation and cloning of the structural gene, *hipP*, for the NTHi pilus serotype 5 and the LKP operon. The invention relates to DNA molecules capable of hybridizing to the DNA sequences of the *Haemophilus influenzae* genome related to the pili. The invention further relates to a DNA molecule which encodes a pilus protein, particularly a tip adhesin protein. The DNA molecules of the invention can be used in a method for assaying a sample, such as a blood sample, for the presence of *Haemophilus influenzae* in the sample. Accordingly, the invention further relates to the use of the DNA molecules as a diagnostic. The invention also relates to a recombinant *Haemophilus influenzae* pilus protein, such as a tip adhesin protein. The protein can be employed in a method for immunizing an animal, such as a human, as a therapeutic or diagnostic.

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-1-

LKP PILIN STRUCTURAL GENES AND OPERON OF NONTYPABLE
HAEMOPHILUS INFLUENZAE

Background of the Invention

Nontypable *Haemophilus influenzae* (NTHi) are primarily noninvasive human respiratory tract pathogens. NTHi can reside in the respiratory tract as a commensal or give rise to local infections, including otitis media, 5 bronchitis, sinusitis, and rarely, pneumonia (Bluestone, C.D., and J.O. Klein, *In Pediatric Otolaryngology.*, 356 (1983); Bluestone and Stool ed. W.B. Saunders Co. Philadelphia.; Musher, D.M. et al., *Ann. Intern. Med.* 99:344-350 (1983)). Several potential adherence factors 10 have been described for *Haemophilus influenzae* (both typable and nontypable) adherence to human cells, including four classes of fimbriae/pili and two high molecular weight proteins with similarity to the filamentous hemagglutinin of *Bordetella pertussis* (St. Geme, J.W., et al., *Proc. Natl. Acad. Sci. USA* 90:2875-2879 (1993)). Pili are bacterial surface antigens. They are protein appendages consisting of a helically symmetrical assembly of major protein (pilin) subunits. Some pili can also carry from two to three minor proteins 20 assembled on their tips. One of these proteins, adhesin, carries the active site for pilus adhesion to specific membrane receptors on human and animal cells.

One class of pili/fimbriae has been widely studied, the long thick pili (LKP) family. LKP pili are expressed 25 by both typable and nontypable *H. influenzae* (Hib). The pili in this family have a characteristic morphology, partially shared adhesion specificity and their structural proteins share amino acid sequences. These pili are hemagglutination positive and mediate attachment to human 30 mucosal cells (Brinton, C.C. et al., *Pediatr. Infect. Dis.*

-2-

mucosal cells (Brinton, C.C. et al., *Pediatr. Infect. Dis. J.* 8 Suppl.:54-61 (1989)). Hemagglutination of human erythrocytes is accomplished via binding to the A_nW_j blood group antigen while binding to epithelial cells involves a 5 sialic acid containing lactosylceramide receptor (van Alphen, L. et al., *Infect. Immun.* 69:4473-4477 (1991)).

The LKP family has been divided into different strain specific serotypes based on reactivity to polyclonal antisera raised against the purified pili. Little cross 10 reactivity among pili serotypes has been observed (Brinton, C.C., et al., *Pediatr. Infect. Dis. J.* 8 Suppl.:54-61 (1989)).

Inhibiting, or blocking, LKP pilus-mediated adhesion by *H. influenzae* to cells can prevent *H. influenzae* 15 diseases. Purified, intact LKP pili have been shown to be vaccine candidates for NTHi otitis media in the chinchilla model, conferring protection against challenge with NTHi strains bearing homologous pili serotype (Karasic, R. et al., *Pediatr. Infect. Dis. J.* 8 (Suppl.): S62-65 (1988)). 20 However, because protection is pilus-specific, for broad protection, a vaccine would be required to be multivalent, including the most frequently occurring serotypes of pili in the natural population of pathogens. LKP pilin structural genes have been cloned and sequenced by several 25 groups (Coleman, T. et al., *Infect. Immun.* 59:1716-1722 (1991); Forney, L.J. et al., *Infect. Immun.* 59:1991-1996 (1991); Kar, S., et al. *Infect. Immun.* 58:903-908 (1990); van Ham, S.M., et al., *EMBO Jour.* 8:3535-3540 (1989)), but only the genes responsible for pili serotypes 1 and 4 have 30 been identified.

Summary of the Invention

The invention relates to the isolation, cloning and sequencing of the pilin gene for the *Haemophilus influenzae* pili serotype 5 (Figure 1), to the sequencing

- 3 -

of the entire LKP1 operon, which is set forth in Table 5 and to the cloning of the LKP10, LKP11, and LKP12 pili. The present invention also relates to DNA molecules (also referred to herein as DNA sequences or nucleic acid 5 sequences) which encode proteins which comprise the *H. influenzae* LKP, particularly a tip adhesin protein. The present invention also relates to DNA molecules capable of hybridizing to the DNA sequences of the *Haemophilus influenzae* genome related to the pili. The DNA molecules 10 of the present invention can be used in a method for assaying a sample, such as a blood sample, for the presence of *Haemophilus influenzae*. Accordingly, the present invention relates to the use of the DNA molecules as a diagnostic.

15 The present invention further relates to recombinant *Haemophilus influenzae* pili proteins, and peptides, specifically a tip adhesin protein. The proteins, or peptides, of the present invention can be used to produce antibodies, both polyclonal and monoclonal, which are 20 reactive with (i.e., bind to) the *H. influenzae* pili proteins, and can be used in diagnostic assays to detect the presence of *Haemophilus influenzae* antibodies, in for example, a blood sample. Such antibodies to also be used as vaccines in methods of passive immunization.

25 The proteins and peptides of the present invention can also be employed in methods for immunizing a mammal, such as a human, against *Haemophilus influenzae* infection and, thus, as a vaccine for the prevention of *Haemophilus influenzae* related diseases, for example, otitis media. 30 In particular, based on the DNA and amino acid sequences presented herein, an adhesin protein, or peptide, vaccine can be constructed which can induce protecting antibodies to *H. influenzae* in mammals.

-4-

Brief Description of the Drawings

Figure 1 is a graphic illustration of the conserved regions of the pilin genes of *H. influenzae* serotypes 1, 4 and 5 (SEQ ID NOS:1-3, respectively).

5 Figures 2A, 2B, and 2C are schematics of the physical maps obtained by restriction enzyme digestion of vectors containing LKP inserts.

Figure 3 shows the amino acid sequence of LKP1 fusion protein. The underline indicates the partial amino acid
10 sequence of the LKP tip adhesin protein that was fused to maltose-binding protein.

Figure 4 is a photograph of a gel showing the identification of LKP1 tip adhesin protein by antibodies reactive with the fusion protein of LKP1 tip adhesin-MBP
15 in Western blotted membranes. Lanes 1 and 2: different preps of purified LKP1 pili with tip protein (47Kd). (A positive reaction was shown between tip protein and the antibody); lane 3: purified LKP10 pili with tip adhesin (47Kd). (The tip protein does not react with the
20 antibody); lane 4: purified LKP11 pili with tip protein (47Kd). (The tip protein does not react with the antibody); lane 5: protein molecular weight markers.

Figure 5 is a photograph of a gel showing the binding activity of LKP1 tip adhesin to human red cell (HRC) ghosts. Lane 1: molecular weight markers; lane 2: purified LKP1 pili with tip protein; lane 3: the pili with HRC ghosts after centrifugation. Tip protein band (47Kd) disappeared due to the binding of tip adhesin pili to ghosts pellet; lane 4: HRC ghosts after centrifugation,
30 used as control; lane 5: purified pili without tip protein (treated with 1% SDS) was incubated with fresh ghosts, showing the same protein band pattern as the pattern of lane 3; Lane 6: purified pili without tip protein. Prior to the gel loading, pili were treated with 1% SDS,
35 exhaustively dialyzed in 25 mM Tris buffer, pH 8.0,

-5-

crystallized by PEG plus NaCl and resolubilized in 25 mM Tris buffer, pH 8.0.

Figure 6 is a photograph of a gel showing the binding activity of purified LKP1 tip adhesin protein to human red cell ghosts. Lane 1: molecular weight markers; lane 2: purified tip adhesin protein with a molecular weight of 47Kd and the protein was removed by 0.1% SDS in 100 mM Glycine buffer, pH 2.0; lane 3: purified adhesin was incubated with fresh human red cell ghosts and pelleted by centrifugation prior to loading the supernatant on the gel. The tip adhesin band disappeared due to the binding to HRC ghosts; lane 4: purified adhesin was incubated with boiled HRC ghosts and pelleted by centrifugation prior to loading the supernatant on the gel. It showed adhesin band with 47Kd, which indicates that tip adhesin protein does not bind to the ghosts pellet; lane 5: supernatant of fresh ghosts after centrifugation. It was used as a control; lane 6: supernatant of boiled HRC ghosts after centrifugation, showing a different soluble protein pattern from that of fresh HRC ghosts, used as another control; lane 7: different prep of purified tip protein incubated with fresh HRC ghosts, which showed the binding between tip protein and fresh HRC ghosts pellet; lane 8: different prep of purified tip protein incubated with boiled HRC ghosts, indicating that the tip protein does not bind the denatured ghosts. The gel was silver stained.

Figure 7 is a photograph of a gel showing adhesin proteins from different LKP type pili with the same molecular weight. Lane 1: molecular weight markers; lane 2: LKP10 pili; lane 3: LKP11 pili and lane 4 to 6: different purified preparation of LKP1 pili. Proteins were stained with silver.

-6-

Detailed Description of the Invention

Described herein, for the first time, is the cloning of the *Haemophilus influenzae* serotype 5 pilin gene and the sequence of the entire LKP1 operon (SEQ ID NO: 4) and 5 the deduced amino acid sequences for six open reading frames (SEQ ID NOS: 5-10). The LKP1 operon, as shown in Table 5, is composed of five separate genes, designated *hipP* (the pilin gene), *hipC* (the periplasmic chaperone gene), *hipR* (the membrane anchor gene), *hipM* (the minor 10 tip associated protein gene) and *hipA* (the tip adhesin gene). These five genes are also referred to herein as *hifA* (for *hipP*), *hifB* (for *hipC*), *hifC* (for *hipR*), *hifD* (for *hipM*) and *hifE* (for *hipA*). Also present on the LKP1 15 operon are an integrase gene, and a peptidase gene. The proteins encoded by these genes of the LKP1 operon and the LKP5 pilin protein are collectively referred to herein as the *H. influenzae* pili proteins.

The present invention encompasses the isolated and/or recombinant nucleic acid sequences encoding the *H. influenzae* pili proteins, or biologically active fragments thereof, described herein. As used herein nucleic acids 20 are also referred to as DNA and RNA, or DNA sequences and RNA sequences, or DNA molecules or RNA molecules. Nucleic acids referred to herein as "isolated" are nucleic acids 25 separated away from the nucleic acids of the genomic DNA or cellular RNA of their source of origin (e.g., as it exists in cells or in a mixture of nucleic acids such as a library), and may have undergone further processing. "Isolated" nucleic acids include nucleic acids obtained by 30 methods known to those of skill in the art to obtain isolated nucleic acids and methods described herein. These isolated nucleic acids include essentially pure nucleic acids, nucleic acids produced by chemical synthesis, by combinations of biological and chemical 35 methods, and recombinant nucleic acids which are isolated.

- 7 -

Nucleic acids referred to herein as "recombinant" are nucleic acids which have been produced by recombinant DNA methodology, including those nucleic acids that are generated by procedures which rely upon a method of 5 artificial recombination, such as the polymerase chain reaction (PCR) and/or cloning into a vector using restriction enzymes. "Recombinant" nucleic acids are also those that result from recombination events that occur through the natural mechanisms of cells, but are selected 10 for after the introduction to the cells of nucleic acids designed to allow and make probable a desired recombination event.

Also encompassed by the present invention are nucleic acid sequences (DNA or RNA sequences) which are 15 substantially complementary to the *H. influenzae* DNA sequences described herein, and nucleic acid sequences which hybridize with these DNA sequences under conditions of stringency known to those of skill in the art sufficient to identify DNA sequences with substantial 20 nucleic acid sequence identity. It is reasonable to predict that DNA sequences identified under such stringent conditions will likely encode a protein (also referenced to herein as a polypeptide, or peptide fragment) with the biological activity of *H. influenzae* pili proteins. A 25 general description of stringent hybridization conditions are discussed in Ausubel, F.M., et al., Current Protocols in Molecular Biology, Greene Publishing Assoc. and Wiley-Interscience 1989, the teachings of which are incorporated herein by reference. Factors such as probe length, base 30 composition, percent mismatch between the hybridizing sequences, temperature and ionic strength influence the stability of nucleic acid hybrids. Thus, stringency conditions sufficient to identify additional *H. influenzae* pili proteins, (e.g., high or moderate stringency 35 conditions) can be determined empirically, depending in

- 8 -

part upon the characteristics of the known DNA to which other unknown nucleic acids are being compared for sequence similarity.

As defined herein, substantially complementary means 5 that the sequence need not reflect the exact sequence of e.g., SEQ ID NO:4, but must be sufficiently similar in identity of sequence to hybridize with SEQ ID NO:4 under stringent conditions. For example, non-complementary bases, or longer or shorter sequences can be interspersed 10 in sequences provided the sequence has sufficient complementary bases with, e.g., SEQ ID NO:4 to hybridize therewith.

The DNA molecules of the present invention can, preferably, encode a functional or biologically active 15 pili protein, such as the pilin gene, *hipP*; the periplasmic chaperon, *hipC*; the membrane anchor protein, *hipR*; the tip associated protein, *hipM* and most preferably, the tip adhesin protein, *hipA*. A "functional or biologically active protein" is defined herein as a 20 protein which shares significant identity (e.g., at least about 65%, preferably at least about 80% and most preferably at least about 95%) with the corresponding sequences of the endogenous protein and possesses one or more of the functions thereof. Biological functions of 25 the *H. influenzae* pili proteins include antigenic structural, and adhesion properties. For example, as described in Karasic, R. et al. (Karasic, R. et al., *Pediatr. Infect. Dis. J.* 8 (Suppl.): S62-65 (1988)), the teachings of which are herein incorporated by reference, 30 pili proteins can be shown to adhere to mucosal cells and erythrocytes. Thus, such adhesion properties can be a measure of biological activity. Also described herein, biological activity can include the antigenicity of the protein, or peptide, resulting in the production of 35 antibodies which bind to the pili proteins.

-9-

The *H. influenzae* pili proteins of the present invention are understood to specifically include the proteins of the LKP1 operon and the serotype 5 *hipP* pilin protein, and proteins having amino acid sequences 5 analogous to these sequences. Such proteins are defined herein as *H. influenzae* pili protein analogs, or derivatives. Analogous amino acid sequences are defined herein to mean amino acid sequences with sufficient identity of amino acid sequence with, e.g., LKP1 tip 10 adhesin protein, to possess the biological activity of tip adhesin. The biological activity of tip adhesin can include, for example, the capability of tip adhesin to bind to specific membrane receptors on human and animal 15 cells. For example, an analog polypeptide can be produced with "silent" changes in the amino acid sequence wherein one, or more amino acid residue differs from the amino acid residues of the LKP1 adhesin, yet still possess adhesion activity. Examples of such differences include additions, deletions or substitutions of residues to e.g., 20 SEQ ID NO:9. Also encompassed by the present invention are analogous proteins that exhibit lesser or greater biological activity of the pili proteins of the present invention.

The present invention also encompasses biologically 25 active protein, or biologically active fragments of the *H. influenzae* pili proteins described herein. Such fragments can include only a part of the full-length amino acid sequence of a pili protein yet possess biological activity. Such fragments can be produced by amino- and 30 carboxyl-terminal deletions, as well as internal deletions. Such peptide fragments can be tested for biological activity as described herein. Thus, a functional, or biologically active, protein includes mutants or derivatives of the endogenous protein wherein 35 one or more amino acids have been substituted, deleted or

-10-

added. Also included are active fragments of the protein. The *H. influenzae* pili proteins, as set forth above, include functional or biologically active pili proteins, such as the pilin structural protein, *hipP*; the 5 periplasmic chaperon, *hipC*; the membrane anchor protein, *hipR*; the tip associated protein, *hipM*; and most preferably, the tip adhesion protein, *hipA*.

The present invention further relates to fusion proteins comprising the pili proteins described herein 10 (referred to herein as a first moiety) linked to a second moiety not occurring in the pili protein as found in nature. Thus, the second moiety can be a single amino acid, peptide or polypeptide. The first moiety can be in an N-terminal location, a C-terminal location or internal 15 to the fusion protein. In one embodiment, the fusion protein comprises a pili protein and either a maltose binding protein (MBP) (SEQ ID NO:11) or glutathione-S-transferase (GST).

The DNA sequences of the present invention can also 20 be used in a recombinant construct for the infection, transfection or transformation of a cell *in vitro* or *in vivo* under control of an appropriate promoter for the expression of functional *H. influenzae* pili proteins, as defined herein, in an appropriate host cell. Such 25 recombinant constructs are also referred to herein as expression vectors. For example, a DNA sequence can be functionally ligated to a suitable promoter (e.g., a constitutive or inducible promoter or the endogenous promoter) introduced into a suitable expression vector, 30 such as pUC19, which is then introduced into a suitable host cell. The construct can also include DNA encoding one or more selectable markers (such as neo, gpt, dhfr, ada, pac, hyg and hisd) or DNA encoding one or more different antigens or therapeutic proteins.

-11-

The construct can be introduced by any suitable means, as set forth above, such as by calcium phosphate precipitation, microinjection, electroporation or infection (such as with an infectious retroviral, herpes 5 vaccinia or adenovirus vector). The host cell can be a eucaryotic or procaryotic cell. Suitable cells include bacterial (e.g. *E. coli*) or mammalian cells. Mammalian cells include primary somatic cells, such as, epithelial cells, fibroblasts, keratinocytes, macrophages or T cells, 10 or immortalized cell lines, such as HeLa or HT1080. The recombinant host cell can then be cultured and, optionally, selected, *in vitro* under appropriate conditions resulting in the expression of the protein. Alternatively, the cell can be transplanted or injected 15 into an animal, such as a human, for *in vivo* expression.

In one embodiment, the present invention relates to LKP type pili-producing *E. coli* recombinants. Such recombinants have been constructed from *Haemophilus influenzae*, as described herein. These single serotype 20 recombinants produced pili in large, easily purifiable quantities. They did not phase vary or become recalcitrant upon subculture and could be grown as *E. coli* in liquid medium with good pilus yields. The single serotype pilus preparations grown and purified from them 25 contained pili identical to those on the parent *H. influenzae* (*Hflu*) strains and contained no other *Hflu* antigens. These preparations are easily standardized for purity, identity, concentration and potency for subsequent mixing into a multivalent vaccine and provides an 30 efficient means of producing pilus for vaccine manufacture. As described herein, single-type-producing *E. coli* recombinant vaccine strains have been constructed for LKP10, LKP11 and LKP12 serotypes.

Multiple serotype recombinants containing two operons 35 on separate plasmids have also been constructed. Single

-12-

colonies of these strains simultaneously expressed, in good quantities, two serotypes of pili. However, these strains were unstable in that, during in vitro subculture, they tended to rapidly lose pilus expression, perhaps 5 because the plasmids used were incompatible. When the two operons are placed on two compatible plasmids these strains are expected to be more stable. The use of stable, high-producing double-expressing recombinant strains could simply production of proteins suitable for 10 vaccine use by reducing by half the number of vaccine strains required.

Good production, concentration and purification methods for *Hflu* LKP pili of different serotypes have been developed and are described herein. Pili can be purified 15 from *E. coli* recombinant cultures producing *Hflu* pili as described for the purification of pili from *Hflu* culture. Both solid phase and liquid phase fermentation methods have been used. The preferred procedure involves mechanical removal of pili from the harvested bacteria and 20 their separation from the bacterial cells by centrifugation. Pili are concentrated and further purified by alternate cycles of longitudinal aggregation (crystallization) of intact pilus rods with soluble impurities removed by centrifugation of the crystals followed by solubilization 25 of the pilus crystals into free pilus rods with particulate impurities removed by centrifugation. Each stage of the production/purification process was optimized for each pilus serotype. To date, nineteen different LKP serotypes have been purified.

30 Alternative pilus purification methods with analytical and industrial utility have also been developed. Using appropriate solvent and column conditions, intact pili can be purified away from contaminating proteins by HPLC or FPLC on molecular sizing, hydrophobic or ion exchange columns.

-13-

These methods are also capable of scale-up for industrial production.

Purification methods for individual pilus proteins have also been developed starting with intact LKP pili. Hflu 5 LKP pilus structural proteins, as deduced from the multiple sequence alignment of pilus gene sequences with other pilus genes, include pilin, small tip minor and large tip minor proteins. The large tip minor protein is referred to as the "adhesin" because it carries the known 10 LKP pilus adhesion specificity for human red blood cells. However, by analogy with other pilus families, the other two LKP pilus structural proteins may also be adhesins with specificities for as yet unknown human receptors. Both 15 pilins and adhesins of LKP pili have been purified in biologically active form.

The pilins are purified in assembled rod form by removal of the minor tip proteins and separation of rods from minors on molecular sizing columns. In their assembled form, the pilin units retain the antigenic 20 specificity of intact pili which is conferred by the exposed surface determinants of the pilin subunits on the lateral surface of the pilus rod. Pilin rods are expected to be equally as effective multivalent vaccine components as intact pili may have advantage of higher purity and 25 possibly reduced side effects.

The adhesin of LKP11 has been isolated and purified in active and soluble form. Its removal from LKP11 pili eliminates the ability of these pili to bind to human red blood cells. In pure form it can bind to human red blood 30 cell membranes. The adhesin band on SDS gels is labeled by antibodies reactive with fusion protein comprised of a fragment of adhesin and maltose binding protein. Purified LKP pilus adhesins may have utility as vaccine components capable of inducing adhesion-blocking or clearing 35 antibodies. The LKP11 adhesin did not cross-react

-14-

antigenically with the LKP1 adhesin on Western blots. Thus, the SDS/PAGE gel similarity of apparent molecular weights found for 3 different LKP adhesins was not predictive of antigenic similarity in this limited two-serotype test. Free adhesins can be tested for efficacy as otitis media vaccines and for their ability to induce adhesion-blocking antibodies. Antiserum to the fusion protein, which labeled the adhesin band on Western blots, did not block adhesion to red cells.

The isolated recombinant proteins of the present invention can be administered to a mammal to protect, or to treat the mammal against *H. influenzae* infection. Isolated recombinant pili protein can be formulated into a vaccine composition, for example, as described in U.S. Patent 5,336,490, the teachings of which are incorporated herein by reference. The protein can also be administered via an infectious construct, preferably a replication incompetent or attenuated viral construct. Alternatively, the protein can be administered via a recombinant host cell (such as, a mammalian cell) which will express the protein in vivo or in a pharmaceutically acceptable carrier. In particular, the recombinant LKP1 tip adhesin protein, a biologically active fragment thereof, or a fusion protein, can be used in a vaccine composition to induce the production of antibodies in a mammal. It is reasonable to predict that such antibodies can protect the mammal from *H. influenzae* diseases.

The vaccine composition may be administered in a singel dose or in more than one dose over a period of time to achieve a level of antibody in the blood which is sufficient to confer protection from *H. influenzae* infection.

Suitable pharmaceutical carriers include, but are not limited to water, salt solutions, alcohols, polyethylene glycols, gelatin, carbohydrates such as lactose, amylose

-15-

or starch, magnesium stearate, talc, silicic acid, viscous paraffin, fatty acid esters, hydroxymethylcellulose, polyvinyl pyrrolidone, etc. The pharmaceutical preparations can be sterilized and desired, mixed with 5 auxiliary agents, e.g., lubricants, preservatives, stabilizers, wetting agents, emulsifiers, salts for influencing osmotic pressure, buffers, coloring, and/or aromatic substances and the like which do not deleteriously react with the active compounds. They can 10 also be combined where desired with other active agents, e.g., enzyme inhibitors, to reduce metabolic degradation.

For parenteral application, particularly suitable are injectable, sterile solutions, preferably oily or aqueous solutions, as well as suspensions, emulsions, or implants, 15 including suppositories. Ampoules are convenient unit dosages.

Modes of administration are those known in the art, such as parenteral, oral or intranasal administration or by cellular implantation.

20 It will be appreciated that the actual effective amounts of the protein in a specific case will vary according to the specific compound being utilized, the particular composition formulated, the mode of administration and the age, weight and condition of the 25 patient, for example. As used herein, an effective amount of protein is an amount of protein which is capable of raising the level of antibody in a mammal to a level sufficient to provide protection from *H. influenzae* infection. Dosages for a particular patient can be 30 determined by one of ordinary skill in the art using conventional considerations, (e.g. by means of an appropriate, conventional pharmacological protocol).

The DNA molecules and proteins of the present invention can be used in *in vitro* diagnostic assays to 35 detect the presence of *H. influenzae* in biological

-16-

samples. In one embodiment, the DNA molecules, or fragments thereof, can be used as probes in an assay for detecting *Haemophilus influenzae* in a sample, such as a blood sample from a mammal, e.g. a human. Such probes can 5 be designed such that they specifically bind to the target sequence (e.g., an *H. influenzae* pili protein).

In one embodiment the DNA probe can comprise the nucleotides of a serotype conserved region of the *H. influenzae* genome, such as the nucleotides encoding a tip 10 adhesin protein. To specifically bind to the target sequence, the probe must be of sufficient length to provide the desired specificity, i.e., to avoid being hybridized to random sequences in the sample. The DNA molecule capable of hybridization preferably contains at 15 least about 400 nucleotides, more preferably at least about 1000 nucleotides, and most preferably at least about 1200 nucleotides. For example, the DNA molecule can comprise at least about 400 nucleotides between about nucleotide 7000 to 7400 of SEQ ID NO:4. The DNA 20 hybridization probe preferably shares at least about around 70% homology or the corresponding sequences of the *Haemophilus influenzae* genome, more preferably at least about 80% and most preferably at least about 90%.

In particular, the DNA molecules of the present 25 invention are capable of hybridizing to serotype conserved regions of the *H. influenzae* genome. A particularly preferred embodiment are DNA molecules that hybridize with the *H. influenzae* region encoding the tip adhesin protein. For example, a DNA molecule can be capable of hybridizing 30 to the gene encoding the tip adhesin protein of serotype 1, preferably the sequence set forth between about nucleotide 6955 to 8265 of SEQ ID NO:4. In one embodiment, the DNA molecule is capable of hybridizing to the genome under stringent conditions, as described 35 herein. The hybridization assay can be performed

-17-

employing known hybridization procedures, such as those described herein. The probe can be, for example, detectably labeled employing known labels in the art, including enzymes, dyes, antibodies and radioactive labels. The probe is preferably immobilized on a solid support (e.g., a membrane).

Alternatively, the DNA molecule can be selected such that it hybridizes to a non-conserved region of the *Haemophilus influenzae* genome. For example, a DNA molecule that hybridizes to the gene encoding the pilin protein can be employed. Such an assay can detect the presence of a particular serotype of *Haemophilus influenzae* in the sample.

A sample which can be subjected to the present assay can be any sample which is suspected of containing or being contaminated with *Haemophilus influenzae*. Examples of such a sample include a blood sample, a nasopharyngeal sample, or an ear aspirate.

The assay can be used, therefore, as a diagnostic for the detection of infection of a subject, such as a mammal (e.g., a human), with *Haemophilus influenzae*. The assay can also be used to detect the presence of contamination of a material with *Haemophilus influenzae*, such as a food, medicament, or biological material.

In another embodiment, the protein can be used in an assay for detecting *Haemophilus influenzae* infection in a sample, such as a blood sample. For example, the pili of a pathogen can be isolated from the sample or recombinantly produced, employing the techniques described herein. One or more of the proteins, or fragments thereof, of the pili can then be sequenced. The sequences can be aligned to and compared with the corresponding protein sequence(s) of SEQ ID NO:4. Homology in excess of 90%, for example, is indicative of presence of the pathogen (i.e., infection) in the sample.

-18-

The pili protein, or a fragment thereof (e.g., a peptide fragment) can also be used in an immunoassay, specifically an ELISA, to detect the presence of antibodies in biological samples (e.g., blood, serum or tissue).

- 5 Such immunoassay can be readily performed by those of skill in the art using well-established techniques to detect antibody bound to LKP pili protein or peptide fragments.

The pili proteins, or fragments thereof (also referred to herein as peptides, or peptide fragments), can also be used to produce antibodies that are reactive with the pili proteins described herein. The term antibody is intended to encompass both polyclonal and monoclonal antibodies. Polyclonal antibodies can be prepared by immunizing an animal with a preparation of crude or purified pili protein using techniques well-known to those of skill in the art. Pili fusion proteins can also be used for immunization. Monoclonal antibodies can be prepared using techniques known to those of skill in the art. These antibodies can be used in diagnostic assays to detect the presence of *H. influenzae* antibodies in biological samples as described above.

The invention is further specifically illustrated by the following examples.

- 25 Example 1: Cloning and Sequencing of the LKP 5 hipP gene and the LKP1 Operon

Materials and Methods

Bacterial strains and plasmids

H. influenzae strains P860295, P861249, and P860688 which express LKP serotypes 1, 4, and 5 respectively, described previously (Brinton, C.C. et al., *Pediatr. Infect. Dis. J. 8 Suppl.: 54-61 (1989)*) were employed. *E. coli* strains MB392 (Kar, S. et al., *Infect. Immun. 58:903-*

-19-

908 (1990)) and HB101 were used as hosts for recombinant plasmids and strain DH5- α was used for cloning steps involving β -galactosidase α -peptide complementation. *Hflu* were grown in brain heart infusion (Dco Laboratories, 5 Detroit, MI) containing 10 μ g/ml hemin (Sigma Chemical Co., St. Louis, MO) and 2 μ g/ml NAD (Sigma) at 37° C. *E. coli* strains were grown in Luria broth (Miller, J.H., In *Experiments in molecular genetics.*, 203 (1972). Cold Spring Harbor Laboratory. Cold Spring Harbor, NY) at 37°C. 10 Where appropriate, antibiotics were used at the following concentrations: ampicillin (Sigma) 100 μ g/ml, kanamycin (Sigma) 25 μ g/ml, and chloramphenicol (Sigma) 20 μ g/ml.

Construction and properties of plasmid pHF1 which expresses LKP1 pili in *E. coli* as described previously 15 (Kar, S. et al., *Infect. Immun.* 58:903-908 (1990)) were employed. Plasmid pPX551 is a pUC18 derivative containing the 1.9 kb XhoI fragment of pHF1 inserted into the BamHI site. Deletion clones of pHF1 lacking the pepN locus were constructed as described in the text. The LKP4 pilin 20 structural gene was isolated by PCR amplification of P860295 chromosomal DNA using primers with the following sequences: for the 5' end of the gene-

5' GTGCTGGATCCGTTCTCTGCATTACATTAGG 3' (SEQ ID NO:12) and for the 3' end- 5' TTAGGAATTCGGAAGCGTTTTACTTTTTGG3' 25 (SEQ ID NO:13). The 5' primer included a HindIII restriction site, underlined in the sequence, and the 3' primer included an EcoRI site also shown underlined. The PCR product was cloned into pCR1000 (Invitrogen, Inc., CA) as per manufacturer's directions. The LKP4 structural 30 gene was subcloned by blunting the EcoRI site with Klenow in the presence of all four dNTPs, and cutting with Asp718 I (an Asp718 I site is located in the vector) releasing the fragment. The LKP4 gene was ligated into HindII-Asp718 I cut pPX191 (a derivative of pUC19 with the bla 35 gene replaced by the cat gene from pACYC184 (Chang,

-20-

A.C.Y., and S.N. Cohen, *J. Bacteriol.* 134:1141-1156 (1978)) to form pPX602.

The LKP5 pilin structural gene was isolated by PCR using the following primers: for the 5' end- 5'-
5 AACGAATTCTGCTGTTATTAAGGCTTAG (SEQ ID NO:14) and for the
3' -AGCTGGATCCTTGTAGGGTGGCGTAAGCC (SEQ ID NO:15). The PCR
product of approximately 1 kb was cloned into pCRII
(Invitrogen, Inc., San Diego, CA and subcloned as a blunt
ended fragment by Klenow treatment of EcoRI ends generated
10 using the vector's flanking EcoRI sites. The LKP5 pilin
gene was subcloned into plasmid pPX191 and orientation
determined by restriction analysis. The LKP5 subclone was
saved as pPX605.

Cloning of hipP genes encoding other LKP serotypes

15 hipP loci encoding serotype 4 and serotype 1 LKP
genes have been described (Kar, S. et al., *Infect. Immun.*
58:903-908 (1990); van Ham, S.M. et al., *EMBO Jour.*
8:3535-3540 (1989)). To determine the serotype specificity
of LKP pili is located within the hipP gene, PCR was used
20 to clone the serotypes 4 and 5 pilin genes from an NTHi
strains expressing these pili. The PCR product for the
LKP4 pilin gene was cloned into pPX191 as described above
and is expressed under control of the lac promoter. The
hipP gene from an LKP5 expressing Hflu strain was isolated
25 by PCR as described and cloned into pPX191 for expression
under lac control.

Oligonucleotide synthesis

The synthetic oligonucleotides used as primers for
PCR amplification and DNA sequencing were synthesized on an
30 Applied Biosystems (ABI) 380B DNA synthesizer using b-
cyanoethyl phosphoramidite chemistry (Sinha, N.D. et al.,
Nucleic Acids Research 12:4539-4557 (1984)).

-21-

Polymerase chain reaction (PCR) amplification

The LKP4 *hipP* and LKP5 *hipP* pilin genes were amplified by PCR from NTHi strains P861249 and P860688 respectively, using standard PCR amplification protocols (Saiki, R.K. et al., *Science* 239:487-491 (1988)).

DNA sequencing

The *hipP* gene contained on plasmid pPX551 and the entire LKP1 operon contained on plasmid pHF1 were sequenced with standard M13 sequencing primers and with overlapping sense and antisense primers. All the DNA sequencing was done on an Applied Biosystems (ABI) 373A DNA Sequencer, utilizing the Tag thermal cycling DyeDeoxy™ Terminator sequencing kit from ABI, part # 901497. The LKP4 and LKP5 serotypes were sequenced directly from the PCR products using the PCR amplification primers and internal synthetic primers based on the LKP1 sequencing study.

SDS-PAGE analysis

Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) was performed in a 70 by 100 mm mini-gel system (Bio-Rad, Richmond, CA) using the method of Laemmli (Laemmli, U.K., *Nature (London)* 227:680-685 (1970)). Samples were reduced with β -mercaptoethanol or DTT in sample preparation buffer and boiled for 5 min. Gels were run at 150 V constant voltage. Separated proteins were detected by staining with Coomassie brilliant blue G-250 (Sigma).

Partial purification of pili

LKP pili were purified according to previously described methods using differential pH solubility (Brinton, C.C., Jr. et al., *Pediatr. Infect. Dis. J.* 8 Suppl.:54-61 (1989)). Briefly, pilated bacteria were

-22-

harvested from liquid culture by centrifugation and washed 2X in phosphate buffered saline, pH 7.2. The bacterial pellet was resuspended in 100 mM tris, pH 10.3, containing 150 mM NaCl at a ratio of 4 ml buffer/g wet weight of 5 cells. Pili were sheared off of the cells by blending in an Oster miniblender for three 3 min bursts at 4°C. Bacterial debris was separated by centrifugation and discarded. The supernatant was dialyzed against 50 mM NaAcetate, pH 5.0 overnight to precipitate pili and 10 denature other proteins. The pellet was collected by centrifugation at 15,000 x g at 4°C and dissolved overnight in 50 ml of 0.01 M CAPS buffer, pH 10.4 with gentle rocking. This cycle of acid precipitation and solubilization in basic buffer was repeated two more 15 times. The final acid pellet was then resolubilized in 0.01 M NaPhosphate, pH 10.4 and non soluble material discarded. This soluble fraction was referred to as partially purified pili.

Sequence of the LKP1 operon

20 The LKP1 operon was sequenced as described above and the full sequence is set forth in SEQ ID NO:4. Sequence analysis identified six potential open reading frames (ORFs) in the LKP operon, including the *hipP* (at about nucleotide 1882-2532 of SEQ ID NO:4) and *hipC* (at about nucleotide 2854-3630 of SEQ ID NO:4) genes. All six ORFs in the LKP operon were identified as homologous to equivalent pilus operon genes in the pilus superfamily, as defined by multiple sequence alignment of proteins. Analysis of sequence alignment was also performed using Entrez 25 Sequences Database Release 10.0 of the National Center for Biotechnology Information (National Library of Medicine, Bethesda, MD). Derived amino acid sequences of the ORFs are shown in Table 5 (SEQ ID NOS:5-10). A function for 30 each reading frame was assigned based on sequence

-23-

alingment analysis. There are five ORFs which appear to be grouped into an operon controlled by the *hipC* promoter region. After the *hipC* (periplasmic chaperon) gene, the second reading frame *hipR* (at about nucleotide 4016-6238 of SEQ ID NO:4) was designated, a membrane anchor protein, the third ORF *hipM* (at about nucleotide 6259-6873 of SEQ ID NO:4) was designated, a tip associated protein, (also referred to herein as a minor tip protein) and the fourth ORF *hipA* (at about nucleotide 6955-8265 of SEQ ID NO:4) 5 was designated, a tip adhesin protein. The pilin gene (*hipP*) and the periplasmic chaperon gene (*hipC*) are transcribed in opposite orientations as in the LKP 4 operon with the promoter region having the previously identified TA repeats(van Ham, S.M. et al., Cell 73:1187- 10 1196 (1993)). Since pHF1 expresses LKP1 pili in *E. coli*, there are 10 TA repeats in the intrapromoter region as described by van Ham et al.. These TA repeats are responsible for phase variation of the LKP pili phenotype, with loss of some of the repeats resulting in loss of 15 20 piliation and a TA repeat number between 10 or 11 allowing expression of the LKP operon. As identiifed on the LKP1 operon was an ORF encoding an integrase (at about nucleotide 1495-1868 of SEQ ID NO:4). Also located on the LKP1 operon was a sequence encoding an enzyme, peptidase 25 (at about nucleotide 8395-9347 of SEQ ID NO:4).

The predicted size of the LKP1 *hipP* gene product is approximately 21.2 kilodaltons, assuming a signal sequence length of 20 amino acids, while the observed molecular weight in SDS-PAGE gels is approximately 27 kilodaltons. 30 Part of this may be explained by the anomalous sequence migration of LKP pilins in general in SDS-PAGE gels (mature LKP4 migrates at a molecular size of 24 kilodaltons while its predicted size is 22.1 kilodaltons) but the exact explanation remains unknown.

- 24 -

Sequence comparison of LKP serotypes 1, 4, and 5 *hipP* genes

This report represents the first sequence analysis of the *hipP* genes encoding LKP serotypes 1 and 5 (Figure 1).

5 The *hipP* gene from an LKP4 expressing *Hib* strain has also been sequenced (van Ham, S.M. et al., *EMBO Jour.* 8:3535-3540 (1989)) and the derived amino acid sequence shows 99% identity with the LKP4 *hipP* derived amino acid sequence contained herein. The *hipP* gene sequences from *Hib*

10 strains Eagan and M43 have been published (Forney, L.J. et al., *Infect. Immun.* 59:1991-1996 (1991)). The LKP1 *hipP* gene should encode a protein of approximately 21.5 kD while the predicted molecular weight of the LKP 4 *hipP* protein is 23.8 kD. The actual *hipP* gene products

15 observed in recombinant *E. coli* are of approximately the correct sizes in Western blots for LKP4 and LKP5, but the LKP1 pilin runs aberrantly at a higher molecular weight than predicted at 26 kD. MacVector software was used to assess homology of these genes, with LKP4 *hipP* and LKP5

20 *hipP* proteins being 70 and 67% identical to LKP1 *hipP*, respectively. The alignment between the sequences is very good at the amino termini of the proteins, with three major areas of sequence divergence in the LKP1, 4, and 5 serotype genes farther into the proteins as shown in the

25 Figure. Since little cross reactivity is observed between anti-LKP1, anti-LKP4, or anti-LKP5 sera with intact pili of a heterologous serotype, the sequences responsible for the serotype specificity of the typing antisera must be located in these regions. By comparison of the sequences

30 in GenBank to the LKP4 sequence, the *H. influenzae* type b M43 pilin (Gilsdorf, J.R. et al., *Infect. Immun.* 58:1065-1072 (1990)) sequenced by Gilsdorf et al. also appears to be an LKP4 serotype gene (data not shown).

-25-

Example 2: Construction of LKP Type Pili-Producing *E. coli* Recombinants

Bacterial strains

Piliated *Hflu* strains used for *E. coli* recombinant construction are LKP11/CB59, LKP10/88-0807 and LKP12/88-0677. Hemagglutination and serum agglutination were examined before making genomic library. *E. coli* strains XL1-Blue^{MR} and HB101 were used as cloning host cell.

DNA library construction and cosmid vector DNA

10 Chromosomal DNA from LKP11, LKP10 and LKP12 were extracted and purified respectively by standard techniques. *Hflu* genomic DNA size is about 1.8×10^6 bp. Chromosomal DNA was partially digested with restriction enzyme *Sau3A* I. Approximately 30kb DNA fragment was eluted from LMTA-15 gel (Sigma) and purified by phenol-chloroform method. The final DNA concentration is about 1ug/ μ l.

20 Vector DNA SuperCos I (Stratagene, La Jolla, CA) was digested with *Xba* I and dephosphorylated with calf intestinal alkaline phosphatase (CIAP). The *Xba* I and CIAP treated vector DNA was then digested with *Bam* HI restriction enzyme. About 6.5kb vector DNA fragment was obtained.

25 LKP11/CB59, LKP10/88-0807 and LKP12/88-0677 DNA fragments were ligated at the *Bam* HI site of the vector DNA SuperCos I, respectively. The ligated DNA was packaged into 1 phage particles using Ciga-pack Gold kit (Stratagene, La Jolla, CA). The host cell for packaging was XL1-Blue^{MR}.

Library screening

30 Recombinant expressed LKP type pili were screened by colony blot method. The concentration of anti-pilius sera from LKP11, LKP10 and LKP12 was 1:1000 dilution. The percentage of positive colony was 40/4200 for LKP11, 9/700

-26-

for LKP10 and 1/600 for LKP12. The cell piliation was examined by EM. The recombinants were verified by further HA and SA assay and they were named CLJ11 for LKP11, CLJ10 for LKP10 and CLJ12 for LKP12 (Figures 2A, 2B and 2C).
5 Recombinants DNA was extracted and transformed to *E. coli* strain HB101 because XL1-Blue cell expresses type I pili. The recombinants DNA size is about 18.5kb for CLJ11. This was obtained by digestion and subsequent ligation using restriction site on insert and vector DNA. CLJ10 DNA is
10 about 25kb and 35kb is for CLJ12. Partial DNA sequence is available for these recombinant inserts.

Example 3: Protocols for the Purification of an LKP Pilus from an *E. coli* Recombinant Strain Using the Liquid Phase Method

15 General Protocol

1. Inoculate recombinant *E. coli* cells in a 3 ml of LB media containing ampicillin and grow at 37°C until the OD 540nm reading reaches 0.6-0.8 (3-4 hours).
2. Transfer the cell suspension to 50 ml of medium and
20 grow at 37°C until the reading at 540 nm reaches 0.8-1.0 (4-5 hours).
3. Transfer the 50 ml of cell suspension to 1L of medium in 2.8L flask and grow at 37°C overnight (16-18 hours) until a reading at 540 nm of 4.0-5.0 is
25 obtained.
4. Harvest cells by centrifugation at 5000 rpm for 15 minutes.
5. Resuspended the cells in 50 mM acetate buffer pH 5.0 and keep the suspension at room temperature for 1
30 hour.
6. Blend at 11000 rpm in large cup, or 14000 rpm in small cup, with omnimixer, ice for 3 minutes.
7. Titrate to pH 8.0 with 1 M Tris-HCl and let stand for 3 hours at room temperature.

-27-

8. Centruge at 12000 rpm for 20 minutes at 4°C. Weigh all pellets and discard.
9. Add 10 ul of DNase and RNase for each 100 ml of prep. Mix thoroughly and let stand for 10 minutes at room temperature.
10. Dialyze against several changes of 50 mM acetate buffer pH 5.0 overnight. If the prep does not reach pH 5.0 overnight, then dialyze longer against more changes of buffer.
- 10 11. Centruge at 16000 rpm for 60 minutes at 4°C to pellet the protein precipitant and pilus crystals.
12. Resuspend the pellet in about 25% original volume with 25 mM Tris-HCl buffer pH 8.0.
13. With gentle stirring add Triton X-100 and EDTA to the prep to yield final concentration of 0.2% and 5 mM. Stir gently overnight at 4°C.
14. Clary the prep by centring at 16000 rpm for 60 minutes at 4°C.
15. Add NaCl and PEG 8000 to final concentration of 0.5 M and 3.0% respectively then incubate and prep over ice for 2 hours.
16. Centruge the prep at 16000 rpm for 60 minutes at 4°C to pellet the pilus crystals.
17. Resuspend pellet in 25 mM Tris-HCl pH 8.0 in 1/3 of previous volume. Use less solution a lesser yield of pilus crystals is obtained.
18. Repeat steps 13 to 17.
19. Resuspend pellet in 25 mM Tris-HCl pH 8.0. Depending on purity and amount of material alternative solubilization and crystallization steps may be continued as needed.
During purification, sample after each step and use SDS-PAGE to examine purity of the samples. Dark field microscopy assay is needed in assistance for purity

-28-

checking. It is necessary to use UV scanning to determine any contamination by DNA or RNA.

Since Triton X-100 has a strong absorbance at 280 nm, it is important to remove the residual of Triton X-100 by 5 crystallization, one time, or more, of pili by PEG and NaCl after purification. This avoids false reading at 280 nm when one determines concentration of pilus preparation by UV method.

Purification of LKP 5 Pili

- 10 1. Harvest in 80 mM PBS pH 5.0 using 5-10 ml/tray.
2. Titrate prep to pH 5.0 with 6N HCl if necessary.
3. Blend with omnimixer over ice for 3 minutes (average speed=9800 rpm) (up to 11000 rpm if possible in larger cups and up to 14000 rpm in small cups).
- 15 4. Titrate to pH 9.0 with 5 M NaOH and let stand for 3 hours at room temperature. It may be necessary to stir gently to prevent pH changes. Monitor pH throughout and adjust if needed. (If cultures were grown in broth, then titrate with a 1 M solution of buffer (Tris) instead of NaOH.)
- 20 5. Centrifuge at 15300 g for 20 minutes at 4°C. Transfer supernatant to clean bottles and clarify a second time as before. Weigh all pellets and discard.
- 25 6. Adjust pH of supernatant to 8.0 and add 10 ul of DNase and RNase for each 100 ml of prep. Mix thoroughly and let stand for 10 minutes at room temperature.
7. Dialyze against several changes of 40 mM acetate buffer pH 5.0 overnight. If prep does not reach pH 5.0 overnight then dialyze longer against more changes of buffer.

-29-

8. Centrifuge at 18600 g for 60 minutes at 4°C to pellet the pilus crystals (crystals not typical for clear pili).
9. Resuspend the pellet in about 25% original volume with 25 mM Tris-CHI pH 9.0 using rubber policeman. Stir gently at 4°C (avoid forming) several hours. Break up large pieces with gentle pipeting as needed.
10. With gentle stirring, add Triton X-100 (2% stock) to the prep to yield a final concentration of 0.4% and add EDTA (25 mM stock) to a final concentration of 5 mM. Incubate overnight at 4°C.
11. Clarify the prep by centrifuging at 186000 g for 60 minutes at 4°C. Transfer supernatant to clean flask.
12. Adjust the pH of the supernatant to below 8.0 using 1 N HCl.
13. Add NaCl (5 M stock) to a final concentration of 0.5 M and PEG (30% stock) to final concentration of 3% then incubate the prep over ice for 0.5 hour. Inspect in darkfield for crystals. Increase time if needed but it is critical not to overexpose pili to PAGE because resolubilization becomes increasingly difficult with increasing times.
14. Centrifuge prep at 18600 g for 60 minutes at 4°C to pellet the pilus crystals.
15. Wash pellet with 40 mM citrate buffer pH 5.0 to remove excess PEG/NaCl. Then centrifuge at 186000 g for 60 minutes (2 times).
16. Resuspend pellet in 25 mM Tris-CHI pH 9.0 in 1/3 to 1/2 previous volume. Solubilize by swirling followed by gentle pipetting. Run sample on a gel to check for purity. If necessary, continue with step 17.
17. Add Triton x-100 to the prep to yield a final concentration of 0.4% and add EDTA to a final concentration of 5 mM then incubate overnight at 4°C (see step 10 for details).

-30-

18. Adjust the pH of the prep to below 8.0 using HCl (between 7 and 8).
19. Add NaCl to a final concentration of 0.5 M and PEG to a final concentration of 3% then incubate the prep over ice for 0.5 hours (see step 13 for details).
- 5 20. Centrifuge prep at 186000 g for 60 minutes at 5°C to pellet pilus crystals.
- 10 21. Resuspend the pellet in 252 mM Tris-HCl pH 9.0 to solubilize pili (see step 16 for details). Check for purity by SDS-PAGE. If necessary, continue with step 22.
- 15 22. Add Triton X-100 to the prep to yield a final concentration of 0.4% and add EDTA to a final concentration of 5 mM then incubate overnight at 4°C (see step 10 for details).
23. Clarify by centrifuging at 18600 g for 60 minutes at 4°C.
24. Add NaCl to a final concentration of 0.5 M and PEG to a final concentration of 3# then incubate the prep over ice for 0.5 hour (see step 13 for details).
- 20 25. Centrifuge at 18600 g for 1 hour at 4°C. Discard supernatant.
- 25 26. Resuspend pellet in Tris-HCl pH 9.0. Depending on amount and purity of material, alternating solubilization/crystallization steps may be continued as needed.
During purification process, monitor pellet material and supernatant by darkfield and/or gel and/or scan. May need to reprocess
- 30 Purity by SDS-PAGE check: Repeat Triton step as needed, but avoid SDS reaction steps in previous protocols because of high losses of pili.

-31-

Example 4: Purification of LKP pili by HPLC and other Column Methods

Besides detergent extraction and PEG precipitation, LKP pili also can be purified by HPLC, FPLC and other column methods. These methods are good particularly for unknown LKP pili. Normally, pili are partially purified by extraction and precipitation first until the pilus solution is clear, concentrated and very small size. the preparation still is not pure as determined by SDS-PAGE, 10 column methods would be the application of the choice. Sizing columns are preferred to be used for this purpose. Prior to loading to a column, treatment for further purification of the pilus sample is important. The detergent used for partial purification of pili should be 15 removed from pilus samples by dialysis or other known techniques. Detergent significantly reduces column separation resolution. Size exclusive column requires a small sample volume.

For HPLC or FPLC, the loading volume of 50 ul to 200 20 ul is recommended, and for other routine LC gel filtration columns, the sample loading volume depends on the length and size of the column. A 1 ml of pilus sample is preferred for a column with a total volume of 50 ml. Since pili have a low absorbance at 280 nm, a higher 25 sensitivity for monitor is recommended. Available protein eluted from column can be monitored at 230 nm. Further purification of proteins can be performed by HPLC. Column methods of purification are also useful for isolation of pilin from pili.

30 Example:5 Protocol for the Purification of an LKP Pilus from an Hflu Strain or E. coli Recombinant Strain Using Solid Phase Method

Generally speaking, recombinant strain expresses pilus structural protein better than parent strain, H flu,

-32-

- does, therefore, it is easier to purify pili from the recombinant cells. However, due to the fact that the *E. coli* recombinant strain expresses the pilus protein as same as the parent *Hflu* does, purification procedures of 5 pilus rods from *Hflu* or from recombinant strain are basically the same. Growth of *Hflu* strain requires chocolate agar media and certain CO₂ and humidity. Growth of *E. coli* recombinant strain needs LB agar media containing ampicillin.
- 10 1. Harvest in 80 mM PBS pH 5.0 using 5 ml/tray. Use a smoothed glass edge to scrape wet cells and then transfer the cell suspension to omnimixer cup. less cells are made surface only use media surface moisture to collect wet cells.
- 15 2. Titrate prep to pH 5.0 with 2 M acetate buffer necessary.
3. Blend at 14000 rpm with omnimixer over ice for 3-5 minutes.
4. Titrate to pH 8.0 with 1 M Tris-HCl buffer and 20 monitor pH change by pH meter. It may titrate to pH with 2.5 or 5 M NaOH instead of Tris buffer, prep contains a lot of wet cells. Be careful to avoid lysis of cells when use NaOH. Incubate the prep at room temperature for 3 hours.
- 25 5. Centrufe at 12000 rpm for 20-30 minutes at 4°C. Weigh all pellets and discard.
6. Add 10 ul of DNase and RNase for each 100 ml of prep. Mix thoroughly and let stand for 10 minutes at room temperature.
- 30 7. Dialyze against several changes of 50 mM acetate buffer, pH 5.0, overnight. If the prep does not reach pH 5.0 overnight, then dialyze longer against more changes of buffer.
8. Centrufe at 16000 rpm for 60 minutes at 4°C to pellet 35 protein precipitate and pilus crystals.

-33-

9. Resuspend pellet in about 25% original volume with 25 mM Tris-HCl buffer, pH 8.0.
10. With gentle stirring, add Triton X-100 and EDTA to prep to yield final concentration of 0.2% and 5 mM.
- 5 Stir gently overnight at 4°C.
11. Clary prep by centrugation at 16000 rpm for 60 minutes at 4°C.
12. Add NaCl and PEG 8000 to final concentration of 0.5 M and 3.0%, respectively, then incubate the prep over
- 10 ice for 2 hours. LKP pili with different length and dimer may be crystallized in different concentrations of NaCl and PEG 8000. Therefore a concentration test for NaCl and PEG to crystalize different pili is important.
- 15 13. Centruge at 16000 rpm for 60 minutes at 4°C to pellet pilus crystals.
14. Resuspend pellet in 25 mM Tris-HCl, pH 8.0 in 1/3 previous. Use even less solution a smaller yield of pilus crystal is found.
- 20 15. Repeat from step 10 to step 14.
16. Resuspend pellet in 25 mM Tris-HCl, pH 8.0. Depending on purity and amount of material, alternate solubilization and crystallization steps may be continued as needed.
- 25 During purication, sample after each step and use SDS-PAGE to examine purity of the samples. Dark field microscopy assay is needed in assistance for purity checking. It is necessary to use UV scanning for finding out any contamination by DNA or RNA.
- 30 Since Triton X-100 has a strong absorbance at 280 nm it is wise to remove the residual of the detergent by one more time crystallization of pili by PEG and NaCI after purication. This avoids false readings at 280 nm when one determines concentration of pilus preparation by UV
- 35 method.

-34-

Example 6: Construction of MBP- Δ 3' Tip Fusion Protein

The genetic fusion was constructed by using PCR primers to obtain a portion of the LKP1 tip gene from pHF1 which would be in frame with the MBP protein gene in the 5 vector pMAL-p2. The primers were designed so that the carboxyl terminal of approximately 100 amino acids of the tip protein would be deleted and replaced with a stop codon. The amino terminal portion of the protein was PRC'd in frame with an appropriate restriction site at the 10 approximate point of the signal sequence cleavage site which was determined by analogy to other bacterial signal sequences and the hydrophobicity profile of the deduced amino acid sequence of the tip protein. The amino acid sequence of the fusion protein is shown in Figure 2. The 15 partial sequence of the LKP tip protein of the fusion protein is underlined.

Expression of the fusion, purification, and antisera production

The protein was expressed in *E. coli* BL21 (an 20 *lon* K-12 strain) grown in SOB broth containing ampicillin at 100 μ g/ml at 28 C after induction with 0.2 mM IPTG. The cells were pelleted by centrifugation and washed 1 time in PBS. The cells were resuspended in 20 mM Tris, pH 7.5 containing 2 mM EDTA and 400 mM NaCl at a 25 ratio of 20 ml/liter of original culture. The cells were lysed by passing through a French pressure cell 3 times and the cell debris removed by low speed centrifugation at 8 times \times g for 20 minutes at 4°C. The supernatant was diluted 5-fold in the same buffer used for breakage and 30 passed over a 15 ml bed volume amylose resin column at 1 ml/min at room temperature. After the lysate was run over the column, the column was washed with 15 bed volumes of the lysing buffer at 5 ml/min. The bound material was eluted using washing buffer containing 10 mM maltose. The

-35-

elution was done with 50 ml of buffer at 1 ml/min and the eluant pooled. The resulting protein mixture was analyzed by SDS-PAGE and Western Blot and anti-MBP sera and found to contain the fusion, breakdown products, and full length
5 MBP. Little other material was detected.

The fusion proteins, MBP and breakdown products eluted as a complex. Mice were immunized with 10 µg doses of the complex using 100 µg MPL as adjuvant.
Immunizations were done subcutaneously at weeks 0, 4, and
10 6 and the mice exsanguinated on week 8. The negative control sera was mouse anti-MBP sera made against purified MBP using the same purification and immunization protocols.

Anti-GST sera

The GST fusion was constructed using the complete LKP tip gene, including the signal sequence. The gene was PCR'd out from PHF1 with the appropriate restriction enzyme sites for insertion into pGEX-3X in frame, and expressed in *E. coli* DH5 α . The cells were grown in SOB containing 100 µg/ml ampicillin and induced with IPTG at 0.2 mM at 37°C for 2 hours. The cells were harvested and washed in PBS, then resuspended in PBS and lysed by passing through a French pressure cell. Cell debris was harvested by centrifugation, and washed 3 times with buffer containing 1% Triton X-Zwittergent 3-14 and the inclusion bodies recovered by centrifugation. The inclusion bodies were solubilized in 5 M guanidine HCl and analyzed by SDS-PAGE. The guanidine concentration was lowered to 2.5 M by dialysis and the soluble inclusion bodies stored at 4°C. The antisera was made by running preparative 10% SDS-PAGE gels and cutting the fusion band out of the gel. The acrylamide-protein band was minced using a scalpel and mixed with MPL (100 µg) and injected into mice 3 times at weeks 0, 4, and 6. Mice were bled at week 8.

-36-

Example 7: Removal, Purification and Identification of H. influenzae LKP Pilus Tip Adhesin Protein

- This is the first demonstration that tip adhesin protein from *H. influenzae* LKP1 pili can be removed
5 without depolymerization of pilus rods. Free tip adhesin protein can be isolated and purified by means of dialysis and prep-electrophoresis. Purified tip adhesin can be identified by the antiserum from a constructed genetic fusion protein, which is from a portion of LKP1 tip gene
10 and MBP (maltose binding protein) gene, using Western blot analysis. Specific binding was detected between the purified tip protein and fusion protein antiserum, which clearly shows that the protein purified from LKP1 pilus prep is LKP1 tip adhesin protein.
- 15 Activity assays with human red blood cell (RBC) ghosts demonstrated that purified tip protein binds to a native ghosts preparation but not does not bind to denatured RBC ghosts, indicating that purified tip protein is biologically functional or at least partially
20 functional.

Removal of Tip Protein from Pilus Rods

1. Dialyze purified LKP1 pili in 200 mM Gly-HCl buffer, pH 2.0 containing 5 M NaCl, at room temperature for 4 to 6 hours.
- 25 2. Transfer the dialysis bag into a 25 mM Tris-HCl buffer, pH 8.0 and dialyze for several hours till the pH of pilus prep reaches to pH 8.0.
3. Add SDS to the pilus prep to a final concentration of 0.1% and incubate in 4°C for 10 hours.
- 30 4. Dialyze the pilus prep in 50 mM citrate buffer, pH 5.0 overnight.
5. Pilus aggregates can be removed by centrifugation and most free tip protein is retained in the supernatant.

-37-

Tip protein can be completely removed by 2% SDS in 25 mM Tris buffer without depolymerization of pilus rods, but the SDS may damage the activity of the protein. 0.1% SDS only removes about 20-30% of total tip protein, however, 5 the protein maintains biological activity. The results also demonstrated that 4M urea and 2M GuHCl in pH 2.0 buffer can partially remove tip protein from pilus rods without depolymerization.

Purification of tip protein

- 10 1. Mix concentrated tip protein with SDS-PAGE sample treatment buffer without the SDS and β -mercaptoethanol. The ratio is 2.5 ml of pilus prep to 0.3 ml of sample treatment buffer.
2. Load the sample to a 12% SDS-PAGE (0.1% SDS) in Prep-15 Cell (Bio-Rad) with the length of stacking gel of 0.8-1.0 cm and running gel of 5cm.
3. Run the gel at 300 volt with cooling system for 6-8 hours, and monitor the elution at 280 nm.
4. Pool the fractions containing tip protein and 20 concentrate.
5. Determine the purity of the pooled fractions by mini-SDS-PAGE. The identification of purified tip protein by anti-KLP1-MBP fusion protein is shown in Figure 4. The binding activity of purified tip protein with human 25 red cell ghosts is shown in Figures 5 and 6. Figure 7 compares adhesin proteins from different LKP type pili by SDS/PAGE.

Example 8: Serotype Analysis

The *Haemophilus influenzae* (*Hflu*) bacterioplex is a 30 differentiated complex of bacterial phases, or cell types, socially organized to facilitate the protein appendages expressed on the surface of *Hflu*, and also secreted from *Hflu* in free form, carrying specific adhesion determinants

-38-

for binding to human cell membrane receptors. Pili adapt pathogenic bacteria to live in vertebrate hosts by mimicking the functions of the host's own proteins. Pilus functions include attaching bacteria to a variety of host cells and tissues and stimulating the host's immune system in ways which benefit the bacteria and damage the host. Pili are transmission, virulence, dissemination, pathogenicity and immunity factors in most bacterial diseases.

The expression of pili is controlled by a genetic switching mechanism, phase variation, in which pilus expression and pilus type are switched on and off at probabilities which vary with and are determined by conditions and signals in the immediate environment of the bacteria. Under some conditions the switching probabilities can be very high, as high as 10^{-2} per bacterial cell division. Under other environmental conditions the probability of the same phase switch can be 10^{-6} or lower. Phase switching is accompanied by both reversible and irreversible rearrangements in the DNA of pilus operons. Phase switching during *in vitro* growth is frequently accompanied by deletions to pilus operon genes such that nonpiliated phases remain irreversibly in that phase.

By purifying *Hflu* pili from different isolates and producing antisera to the purified preparations distinct LKP pilus serotypes have so far been identified. The expression of the different serotypes is used as a marker to identify the different piliation phases of the *Hflu* bacterioplex.

-39-

TABLE 1

| | | L=1 | L=2 | L=3 | D=3 | D=4 |
|----|-----------------|------|-----|-----|-----|-----|
| 5 | LKP1 | N=4 | 0 | 0 | 4 | 0 |
| | LKP2 | N=2 | 0 | 1 | 1 | 0 |
| | LKP3 | N=0 | 0 | 0 | 0 | 0 |
| | LKP4 | N=1 | 0 | 1 | 0 | 0 |
| 10 | LKP5 | N=5 | 0 | 1 | 4 | 0 |
| | LKP6 | N=12 | 0 | 2 | 8 | 1 |
| | LKP7 | N=3 | 0 | 0 | 2 | 0 |
| | LKP8 | N=0 | 0 | 0 | 0 | 0 |
| 15 | LKP9 | N=0 | 0 | 0 | 0 | 0 |
| | LKP10 | N=26 | 1 | 8 | 17 | 2 |
| | LKP11 | N=22 | 0 | 6 | 16 | 0 |
| | LKP12 | N=12 | 0 | 3 | 7 | 2 |
| | LKP13 | N=0 | 0 | 0 | 0 | 0 |
| 20 | LKP14 | N=9 | 1 | 2 | 6 | 1 |
| | LKP15 | N=6 | 0 | 5 | 1 | 0 |
| | LKP16 | N=9 | 0 | 4 | 5 | 3 |
| | LKP17 | N=17 | 0 | 6 | 11 | 2 |
| | LKP18 | N=12 | 1 | 4 | 7 | 1 |
| 25 | LKP19 | N=3 | 0 | 1 | 3 | 0 |
| | LKP20 | N=15 | 1 | 6 | 8 | 3 |
| | Total Strains = | 77 | 4 | 50 | 99 | 15 |
| | | | | | | 136 |

25 L=1 is length <0.2 μ
 L=2 is length <0.2 μ <0.5 μ
 L=3 is length <0.5 μ
 D=3 is 3nm diameter ("thin")
 D=4 is 4nm diameter ("thick")

30 The frequency of each LKP serotype was determined for all serotypable cultures and for all cultures expressing

-40-

by counting types on both single expressors and multiple expressors. Sixteen of the 20 serotypes were found on typically LKP pilated cultures and 90% of these cultures were serotypable in the 20-type system. The frequency
5 distribution of serotypes for these cultures is shown in Table 1.

Three different LKP pilus operon genes were selected, the pilin gene, anchor gene and adhesin gene, which had all exhibited sequence similarity among different
10 serotypes in multiple sequence alignments, but were also characteristic of *Hflu* LKP pili. Sequences were selected from these genes that would serve as suitable primer sequences flanking each gene for use in a PCR reaction.

15 LKP1 Pilin: HF2 5' >AGCTGGATCCTTGTAGGGTGGCGTAAGCC<3'
(SEQ ID NO:16)
HF1 5' > AACGGATTCGTTGCTGTTATTAAGCCTT<3'
(SEQ ID NO:17)

20 LKP1 Anchor: R5 5' >GCCGCACCTTGATGAACG>3'
(SEQ ID NO:18)
R3 5' >GGCAAATACGCACCGCTAAAT>3'
(SEQ ID NO:19)

LKP1 Adhesin: A5 5' >CGGACGAAGATGGTACAACGA>3'
(SEQ ID NO:20)
A31 5' >CCAAGCTTGGCCCGACATTATTATTGATATGACA>3'
25 (SEQ ID NO:21)

All three pairs of primers were synthesized and used in a PCR reaction to amplify segments of DNA extracted from *Hflu* isolates.

30 Data showing the presence of LKP pilus operons in tested *Haemophilus influenzae* strains is shown in Table 2.

-41-

| TABLE 2 | | | | | | |
|--|-----------------|-------|----------|-------|-------|----------------|
| CORRELATION BETWEEN THE PRESENCE OF LKP PILUS OPERON GENETIC MATERIAL IN <i>H. INFLUENZAE</i> ISOLATES AND THE EXPRESSED LKP PARAMETERS OF PILIGATION AND HEMAGGLUTINATION | | | | | | |
| | LKP Parameter | Total | PCR Done | PCR + | PCR - | Fraction PCR + |
| 5 | Pilus Length 0 | 74 | 68 | 59 | 9 | 59/68 |
| | Pilus length 3 | 101 | 93 | 82 | 11 | 82/93 |
| 10 | HA+ | 148 | 139 | 115 | 24 | 115/139 |
| | HA- | 166 | 149 | 119 | 30 | 119/149 |
| 15 | Pilus Diam. 3 | 40 | 38 | 28 | 10 | 28/38 |
| | Pilus diam. 4 | 172 | 159 | 136 | 23 | 136/159 |
| 20 | Serotypable | 189 | 173 | 149 | 24 | 149/173 |
| | Not serotypable | 54 | 63 | 53 | 10 | 53/63 |
| 25 | | | | | | 86% |
| | | | | | | 84% |

1. Pilus length 0 means nonpiliated.
 2. length 3 means >0.5 microns (longest, typical of LKP pili).
 3. HA+ means positive for hemagglutination of human red blood cells; typical of LKP pili. (These isolates are not recalcitrant by definition.)
 4. HA- means negative for hemagglutination of human red blood cells; typical of SNN pili. (These isolates are recalcitrant since all isolates were hemadsorbed at least once.)
 5. Pilus diameter 3 means the isolates express pili with diameters typical of SNN pili.
 6. Pilus diameter 4 means the isolates express pili with diameters typical of LKP pili.
 7. Serotypable means the isolates agglutinate under standard conditions with at least one of the LKP pilus typing antisera in the 1-20 system.
 8. Not serotypable means the isolates do not agglutinate with any of the LKP pilus typing antisera in the 1-20 system.

Example 9: Hybridization Assay for *Haemophilus Influenzae* Assay Probe Construction

An approximately 1100 bp fragment from plasmid pHF1 (Karasic, R. et al., *Pediatr. Infect. Dis. J.* 8 (Suppl.):S62-65 (1988)) which contains the LKP1 serotype operon was amplified by PCR using primers which hybridize at the 5' and 3' ends of the *hipA* gene. This gene encodes the tip adhesin protein of the LKP1 pili. The PCR reaction included digoxigenin labeled dUTP along with the

-42-

four dNTPs to label the PCR reaction product with digoxigenin. This probe was electrophoresed on an agarose gel and purified by cutting out the ~1.2 kb band and extracting the DNA by standard methods. The probe was 5 redissolved in 30 μ l of appropriate buffer.

Hybridization Assay

Eleven randomly chosen *Haemophilus influenzae* clinical isolates were grown on BHI-XV plates at 37°C with 5% CO₂ and also streaked onto BHI agar. All isolates grew 10 only on the BHI-XV plate, indicating that they were *H. influenzae*. The isolates included 2 *Hib* strains and 9 *NTHi*. The strains were inoculated onto a nylon membrane placed onto BHI-XV agar. Five clinical isolates of another respiratory pathogen, *Moraxella catarrhalis* were 15 also spotted onto the filter. The bacteria were grown overnight at 37°C in 5% CO₂. After growth, 2 *Bordetella pertussis* strains were spotted onto the filter. Filters were processed for colony hybridization according to the method of Maniatis et al. (*Molecular Cloning: A 20 Laboratory Manual*, 1991, Cold Spring Harbor Laboratories, Cold Spring Harbor, NY). Filters were blocked in pre-hybridization solution as described by Boehringer-Mannheim for the Genius™ system at 65°C for 3 hours. Colony debris was removed by gentle rubbing with wet paper towels. The 25 probe, 30 μ l, was added to 5 ml of pre-hybridization solution and boiled for 10 minutes to denature the DNA. Probe was immediately added to the filter and allowed to hybridize overnight at 65°C. Filters were washed in 2X SSC, 0.1% SDS, 2X for 5 min/wash at room temperature 30 followed by 2, 15 minute washes with 0.2X SSC, 0.1% SDS at 65°C. Bound probe was detected using alkaline phosphatase labeled anti-digoxigenin antibodies as described by the manufacturer. Results are shown in Table 3.

- 43 -

Table 3 HYBRIDIZATION OF dig-LABELED LKP 1 TIP PROBE TO RANDOM CLINICAL ISOLATES

Number of Positive Results

| Bacterial Strain | Strong Signal | Weak Signal | No Signal | # Total |
|-----------------------|---------------|-------------|-----------|---------|
| <i>H. influenzae</i> | 4 | 4 | 3 | 11 |
| <i>M. catarrhalis</i> | 0 | 0 | 5 | 5 |
| <i>B. pertussis</i> | 0 | 0 | 0 | 2 |

The probe was specific for *H. influenzae* with no hybridization seen with either *M. catarrhalis* or *B. pertussis*.

Hybridization Assay of Nontypable Strains of Haemophilus influenza pili

Ten LKP pili expressing NTHi strains which express differing serotypes of LKP pili, along with Hib Eagan were grown on a nylon filter overlayed onto chocolate agar at 37°C in 5% CO₂. An additional NTHi isolate was also included. After growth, two strains appeared yellow on the filter which was suggestive of non-Haemophilus bacteria, so they were tested by growth on BHI and BHI-XV. This experiment showed them to be contaminants and not NTHi. The filter was removed from the agar and processed as described above. The probe from the first experiment was reboiled and added to the filter as before, except that the hybridization temperature was lowered to 62°C. The filter was washed as before except that the wash temperature was also 62°C. Bound probe was detected as above. Results are shown in Table 4.

- 44 -

Table 4. HYBRIDIZATION OF dig-LABELED TKP TIP PROBE TO LKP TYPE STRAINS

| LKP Serotype | Signal with probe | No signal with probe | ID of strain |
|--------------|-------------------|----------------------|--------------|
| 5 | Strong | | NTHi |
| 2 | Moderate | | NTHi |
| 9 | Strong | | NTHi |
| 1 | Strong | | NTHi |
| 6 | Moderate | | NTHi |
| 13 | Strong | | NTHi |
| 4 | Strong | | NTHi |
| 7 | Moderate | | NTHi |
| | | X | Contaminant |
| | | X | Contaminant |
| 10 | Weak | | NTHi |
| 4 | Strong | | Hib |

The results set forth above establish that the DNA probes hybridized selectively to *Haemophilus influenzae*.

Equivalents

Those skilled in the art will recognize, or be able to ascertain using not more than routine experimentation, many equivalents to the specific embodiments of the invention described herein. Such equivalents are intended to be encompassed by the following claims.

- 45 -

TABLE 5

AAGCTTGCATGCGTCAGGTCGACTCTAGAGGGATCATTCATTGTGTTTATCTTTAATAAACACCAAGGTGAGGTAGAAATATTTCAGTTGATC
AAGCAAGGATTTTGGCTAAAAGAATGGCTAATAATCCAATACATGTTGATTAACGAAGTTTATGATTGCTGAGTAATTCAAGTCAAAGGC
TTTTTTOCCAGGGTICAATTMCOGGGCGTGATGATGCGATTTCAGGTAAAGTCAAAAACTGGGCCATTGAAGGCTAAGGGTTCAACATAAATATCT
AAAGGTGCACCAAGOGTAACCTAACATTCTGCGAGGTGCGAGAACATAACGGTTGGGTATAAGGTGGAGTTTTCGATAATTATTCT
CGTTAAATTACGAAAAAAACAACOGCACTTTAAAGTGCGGTCAGATCTGAAGATATTTTATGTCGGTGGATCGGGATTGTCAGTACAGCACG
AGTTTGGCTTTCACGGAAGATTGCAAGOGTGAAGCAATTCTGCATCOCAAACCTGCTAGAATTGGCTGCTAACAAACCCAGCATTGCGGCG

CTGCAGAGCCAATCGTAATGTTGGACTGGAAATOCCTTGGCATTCGCACAAATGAATAAAGGCTATCACCACCTAACATAGAACCTTT
ACTGGCACCCCCAGCACTGGCACAACTGTITGGCTGOGATCATAACAGGTAATGTGCCCGACCGCTGCACCGAATAATTACTTTATAGCC
ATTTTTTGTGCAATTGGCAAATTGAAAAGTMTATCAGGOGTAGCGATGGGAGAGACGACTTCCACATGATAAGGCACGTTAATTCACTA
AAATCTGAGTTGCCCTTGCAAGTAGACCCAAATCACTTTTGACCCCATCACAAACGGCAATTGTGCAAGTTTGACATGCTATTCTCAATT
TCTAATTAAAAACGTGGTGTAGAATAGCATAGTATATCGAGCAAACGTTTGCTATTATGTAOGTATTAAATGGGATTATTATTAATT
ATTTGATTTTAAATTAGTAACATACATGATAACAAATTAAATGGGOGATAGTTATATGGGACGAACTGAAAAATTATTAGATAAGCTGCA

CAATCAAATCTACATTAAATTGGAAATGAAATTAGTTCTTGTAGCTAACAGGTTATGAAAAGCGAGAAATGGCAGGTCTCGAGTGAGATT
TTATAATAGAACACTCGAACATATGATTTCGTACACAAGGCTCATCTGAAAATTATATTAAAGGCGGTGTTAAAGTCAGTGAAAGAATCAT
TAAAACAGGTAGGTATTCTATGAAGTTATTAAATTATAAGGTTATGTTGGCAGCATTGAGGGGGATTAGAAAACAATATATTATTGCGAAC
TIGCTTACATTCTGTGATTAGTGACTTACGAAGCAGACTCATTATCTGAGTTAGAAAAAGAATTTCATCAATCTGTTGATTATTTACAAGAT
TGTGTTGGAAATTAGGTAAAGAACCGAATAAGCCATTAAAGGTTGTTAAATGTACGAATTGGCGAGGAATTGCATAGAGAACGATCATAGC
TGGCGATCGTTCTTAATGCTTTCGTAGCGGAAGCAATTAAAGAAAAATTTCGTGAAAACCAGTTAAGATAACAAAAGTATTACAT
TTTTTTTCATCACGTAGGCTGGGCGTAAGCCCCATGTAGAGACATAAAAAAGATTGTTAGGCTAGGCGTAAGCTCACTGGATACATATAAAA
AGATTTGTAGGGTGGGCGTAAGCCCCAOGCAGGATATAACAAAACAOGTGGGCTTAGATTGCAATTACATTAGGAATTATGTAAGCAATTGCAAA

TCAACTGAGGATTCTACTTACCAAGCTCCGCTTGAGCTGTGCAATAGTATAGTGTAAATTACACATTGGTTAACCGTTAATTGT
 4spVal Ser Ser Glu Val Lys Glu Ala Glu Ala Glu Ala Thr Ala Tyr Tyr Arg Ala Leu Lys Val Asn Asn Glu Val Lys Asn Leu Thr
 AGCTTTCTCTGAAATATGATTTCATTCAGTTGTTGTTGCCAACGTCATTGCTATGCCTAAAATCTGTGTTCCGGTGCAG+ AA
 4Ala Lys Glu Ser Leu His Asn Val Thr Glu Glu Thr Ala Val Asp Asn Thr Asn Ser His Thr Phe Asp Thr Thr Glu Asn Glu Val Val
 CTTCAATTGCATCTGTAACCATAGCATAAAGCTGGATATTAACATTCCTGTCAGCATCATTCCCTGATTTTGATTTTAAATGTATATTCA
 4LGl uLeu Leu Ala Asp Thr Glu Asn Ala Asp Phe Leu Glu Leu Asn Val Asn Glu Ala Asp Asn Glu Ser Lys Thr Asn Lys Leu Thr Tyr Glu uA
 TTATTTCTATCTGCATTTTCAAGAATAGAARTAAAGCTCCAACTTTTGTTGCAACAGGCTTATTATTAGTAGTGTAGTGTAGAACAAATTTC
 4snAsn Glu Asp Ala Asn Lys Trp Ser Tyr Phe Tyr Ala Glu Val Lys Thr Ala Pro Lys Asn Asn Thr Thr Thr Cys Asn Glu u
 TAAATTAAATGTAATGGTGTGGCATCGCTGTATCTTTAGTTAAATGATTTAACCCACATCATTTAAACTACGCTCATATTTCAC
 4LeuAsn Leu Thr Phe Pro Thr Pro Met Ala Thr Asp Lys Lys Thr Lys Leu His Asn Lys Glu Val Asp Asn Leu Val Val Ser Met Asn Lys Se

TATCCGTTTCACTTACAAGTATTCTAACAAACCTTACCAAGAAAGTAACCTTACCAAGATGTTTCAGTACTTACTTGAGGATCAGCAGCATTC
 ↣rAspThrLysValLysCysThrAsnGluValValLysGlyPhePheThrValLysGlySerThrGluThrSerValGlnProAspAlaAlaAsnT
 GTTGCAAATGCCAATAAAATTAAAGCTACCAAGAAAGTGTGTTTCTATAATAAATTGCTCCATAAAAGAGGTTGTGCCTTATAAAATAAGGCATAAA
 ↣ThrAlaPheAlaLeuLeuIleLeuSerGlyLeuLeuThrLysLysMetIlePheGlnGlyMet

AGATTAATATAAACCGTTTATTAAAATGCCAAAGGCTTAATAAACAGCAAACTTTGTTTCCCAAAAAGTAAACTCTTCATTATATA

TATATATATATAATTAAAGCCCTTTTGAAAAATTTCATATTTTTGAAATTAACTCGCTGTAGGTTOGGTTTTTGCACATGGAGACATATAA
AAAAAGATTCTGAGGTGGCGTAAGCCACCGGAACTCATCAAACAATGTAATGTTGTATTAGGCAOGTGGCTTATGCCTGCCCCAGGG
GAAATCGATAAAAGATAATAATCGCTTTAGCCAGTTATGCAATTATCGCTAAATGCCGAABACATCGTTAAATAAAAACACTTTTATTTTT

▶ MetAsnLysAspLysTyrGlyLeuSer ProValTyrGlyPheAsnTyrValGluMetGlyLysThrMetPhelysLysThrLeuLeuPhePh
 TACCGCCTACTTTTTCGCGCACTTGTGCAATTTCAGCCAATGCAAGATGTGATTATCACTGGCACCAAGGTGATTATGCCGCTGGCAA
 ▶ eThrAlaLeuPhePheAlaAlaLeuCysAlaPheSerAlaAsnAlaAspValIleIleThrGlyThrArgValIleTyrProAlaGlyGlnLysA
 ATGTTATCGTGAAAGTTAGAAAACAATGATGATTGGCAGCATGGTGCAAGCTGGATTGATAATGGCAATCCAAATGCGATCCAAAATAC. CC
 ▶ sValIleValLysLeuGlyAsnAsnAspAspSerAlaAlaLeuValGlnAlaTrpIleAspAsnGlyAsnProAsnAlaAspProLysTyrThr

AAAACCOCTTTGTGATTACCCGGCTGTGCTCGAGTGGAAAGCGAAATCAGGGAAAGTTGGGATTACGTCACAGGCAGCGAGCCTTAC
 > LysThr ProPheVal IleThr ProProValAlaArgVal Gl uAl aLysSer GlyGlnSerLeuArgIleThr PheThr GlySer Gl uProLysPr
 TGATGATCGGAAAGCCTCTTTATTTAATTGGTAGATATTCCGCGGAAACCTGATGGGCAATTCTGGCAAACACGGGAGCTTTATGCCAA
 > oAspAspArgGl uSerLeuPheTyrPheAsnLeuLeuAspIleProProLysProAspAlaAlaPheLeuAlaLysHisGlySerPheMetGl nI
 TTGCCCCATTGCTCAAGTTGAAGTTTATGGCCTGCGAAACTCTGATGGATTCTGATGCAATGAAAAAGTAGTGTAAAGCCACA
 > IeAl aLysArgSerArgLeuLysLeuPheTyrArgProAlaLysLeuSerMetAspSerArgAspAlaMetLysLysValValPheLysAlaThr
 CCTGAAAGGGGTGTTGGTGATAATCAAACCCCTTATTATATGAACTACATTGGTTGTTACATCAAATAAACCTGCGAAAATGTCAAAATGGT
 > ProGl uGlyValLeuValAspAsnGlnThrProTyrTyrMetAsnTyrIleGlyLeuLeuHisGlnAsnLysProAlaLysAsnValLysMetVa
 TGCCCCCTTTCTCAAGGGCTATTGAAAGCCAAAGGGTGGTTCTGGCGATAAAATGAAATGGTATTGGTTAATGATTAOGTGCGACCAAG
 > IAIaProPheSerGlnAlaValPheGl uAl aLysGlyValArgSerGlyAspLysLeuLysTrpValLeuValAsnAspTyrGlyAlaAspGl nG
 AAGGGCGAACGOCATCGCTCAATAATAGCGAACACTAGTGTAGGGTGGGTTAGACOACCGATAACCATAACAAAGTGGCTGAACGCCACCCCTAC
 > IuGlyGluAlaLysAlaGln
 AACCCACAAAGAACGATTAATCTGTGAAACAAAAATTTCCTAAATAAAATGGGTTGCTGTTCACTGCTATGGCAAATTCCTTACGCTG

- 46 -

Table 5 (cont.)

GGCGGGAGATCAATTGATGCCCTCCTTGGGAGATGGTGGGTGGGGTTGATTTGCCGATTTAATGAAAAATGCCGTGTTACCA
 GGGGTTATGAAGCTCAAATCTATGTGAAATTGAGAAAAGGCGTAAGOGATATTATTTGCTGATAATCTGOCACAGGTOGGACAGAATT
 ATGTTTACGCTAACTCAAGAAATGCTGGATTGATGGATGAAGCCATTGGAATCGCCCAATTCAAGAGATGAEACTTGTGTTGCTT
 ▶ Met LeuAspLeuMetAspGluAlaIleValLysSer ProAsnSer GluAspAspThr CysVal PheAlaS

CTGATGCTATTCTAAAGGCACGTTGAATATCAAAGGGGAAATGAAATTGAGCTCCCAAGCTCTCACTATTGCCGACCAAGA
 ▶ erAspAlaIleProLysGlyThrPheGluTyrGlnSerGlyGluMetLysLeuGluLeuProGlnAlaLeuThrIleArgArgProArg
 GCGTATATTGGCCCATCTGGCTGGCAAATGGCACCAATGCGCTTTGCAAATTACGATATCAACTATTATGTTCTGGTAATCCGAAAGTAA
 ▶ GlyTyrIleAlaProSerArgTrpGlnThrGlyThrAsnAlaAlaPheAlaAsnTyrAspIleAsnTyrTyrArgSerGlyAsnProGluValI
 ATCCGAAAGTTGTTATGTTGGCTGGCTACTGGCATGGCTATGGCAGTTTACCGTTTGAAACCA
 ▶ sSerGluSerLeuTyrValGlyLeuArgSerGlyValAsnPheGlyAsnTrpAlaLeuArgHisSerGlySerPheSerArgPheGluAsnGlnS

CTAGCTGGGTTTACTGATAAGGCRAAAATCATTAGAACGTTGGGATACTTACAAACGAGATTTCGCCCTGCTTCGCGCAATGTCAC
 ▶ erSerSerGlyPheThrAspLysGlyLysAsnHiS TyrGluArgGlyAspThrTyrLeuGlnArgAspPheAlaLeuArgGlyAsnValThr
 GTTGGGATTTCAGCACTGCCGATTGGGAAATTGGTATGGCTTGGCTTGGCTATGATAGATAATGCTTGGCCATCACA
 ▶ ValGlyAspPhePheSerThrAlaArgIleGlyGluAsnPheGlyMetArgIleAlaSerAspAspArgMetLeuAlaProSerGly
 ACCTGGTTTGGCCAGTGGCTGGCGTCCCACAAACAGOCACAGTCAGCATCAAACAAATGGCTATAOGATTATCAAATCACCGTC
 ▶ nArgGlyPheAlaProValValArgGlyValAlaAsnThrAsnAlaLysValSerIleLysGluAsnGlyTyrThrIleTyrGlnIleThrValP
 COCGAGGCCCTTCGTGATTACGATTGTTATGOCAGGGTTATGGCGGATTAAACGGTGGAAATCCAAGAAAGTGTGGTAAAGTGGCTCA
 ▶ roAlaGlyProPheValIleAsnAspLeuTyrAlaSerGlyTyrSerGlyAspLeuThrValGluIleGlyGluSerAspGlyLysValArgSer
 TTATGTCGCTTTCTAATCTGGCCCGTTAATGGGTGGGGCATTCGTTATCAATTAGCTGGCGAOGTTACGAAATGACAGCCGAC
 ▶ PhelIleValProPheSerAsnLeuAlaProLeuMetArgValGlyHiSLeuArgTyrGlnLeuAlaGlyGlyArgTyrArgIleAspSerArgTh

CTTGATGAACTGTGTTACAAGGGTGTGCAATATGGTTAACTAATCATCTCACGCTGAATCAAGCTGTTTATCACGTCATTATGTC
 ▶ rPheAspGluArgValLeuGlnGlyValLeuGlnTyrGlyLeuThrAsnHiSLeuThrLeuAsnSerSerLeuLeuTyrThrArgHiS TyrArgA
 CAGGGCTGTTGGTTGGTTAAATACCGCGATGGGGCTTCTCTGATGCCACTTGGCTGCAOGCTGATTTCGCTAAACATGTCAGC
 ▶ IaGlyLeuPheGlyPheGlyLeuAsnThrProIleGlyAlaPheSerAlaAspAlaThrTrpSerHiSAlaGluPheProLeuLysHiSValSer
 AAAACGGCTACAGCTTGACGGCAGTTAGTATTAACTCAATGAAAGTGGCACCAATATCACGTTGGCAGCCTATGCCATTCTCACC
 ▶ LysAsnGlyTyrSerLeuHiS GlysSerTyrSerIleAsnPheAsnGluUserGlyTyrAsnIleThrLeuAlaAlaTyrArgTyrSerSerArgAs
 TTTTACACTTAAGCGACACCATGGCTTAAACGGACTTACAGACAATTAGCGGTGGTATTGCTGAAATTACCGOCACAAAAATCAGT
 ▶ pPheTyrThrLeuSerAspThrIleGlyLeuAsnArgThrPheArgGlyAlaTyrLeuProGluIleTyrArgProLysAsnGlnP
 TTCAAGTGAGTTAAAGCCAAAGCTGGGAAATGGGAAATCTCTATCTCAGGACAAACCTATAATTATGGGAAACGTGGCACGAAATCG
 ▶ heGlyValSerLeuSerGlySerLeuGlyAsnTrpGlyAsnLeuTyrLeuSerGlyGlyTyrAsnTyrTrpGlyLysArgGlyThrAsnThr
 CAATATCAAGTTGCCATTCAACAGCTTACACATTCTAATTACTCTGAAACCTCTCACAGAGTATTGATAAAAGAAACGGCAAACGTGACAA
 ▶ GlyTyrGlyValAlaTyrSerAsnSerPheHiSleuAsnTyrSerValAsnLeuSerGlySerIleAspLysGlyUserGlyLysArgAspAs

CAGCATTTAAAGCTCAGCCTGCCATTAGGGATAACCATCTGAGATAGTAGTTTCTGGCTGGTAACGATAATTAAACCAACGACTTG
 ▶ nSerIleTyrLeuSerLeuSerLeuProLeuGlyAspAsnHiS SerAlaAspSerSerTyrSerArgSerGlyAsnAspIleAsnGlnArgLeuG
 CGCTAAATGCTCTTGGTGAACGTCATCAATGGAGTTAGGTATTAACGCTTACCGCAATAATCAAGGCTATGCCAGTTATGACGCTAAATCTT
 ▶ IyValAsnGlySerPheGlyGlyArgHiS GlnTrpSerTyrGlyIleAsnAlaSerArgAsnAsnGlyTyrArgSerTyrAspGlyAsnLeu
 TOGCATAACAACTAGCATGGTAGTACCGTGCCTTATTACGTTGATAGCCTCAAAATGCTOCATCTCACGGCGCAAGCGTGTGCGT
 ▶ SerHiSAsnAsnSerIleGlySerTyrArgAlaSerTyrSerArgAspSerLeuLysAsnArgSerIleSerLeuGlyAlaIleValVa
 GGGCACAACACGGTATTACCTTAAGCCAACCTGTTGGCGAAAGTTTGCCATTATTCAOGCCAAGATGCCAGGAGCAAAGTGGAAATCAG
 ▶ IAIaHiSlysHiS GlysIleThrLeuSerGlyProValGlyGluUserPheAlaIleIleHiSAlaLysAspAlaAlaGlyAlaIleValGlyUserG
 GTGCCAATGTGAGCCCTGATTATTGGCAATGGGTTATGCCATTACACCAGCCGATGAAATCAATTATCGGTATCAATOCATCTGATGCG
 ▶ IyAlaAsnValSerLeuAspTyrPheGlyAsnAlaValMetProTyrThrSerProTyrGlyIleAsnTyrIleGlyIleAsnProSerAspAla
 GAGGGCGAATGTCGAATTGAGCCACTGAAACGCAAATCATTCTGGCTGCAAAATTCAATTAGCTTGTAGATTGCTTGGCAOGGGCAAACATCAAT
 ▶ GIAIaAsnValGlyUserPheGlyAlaThrGlyArgGlyIleSerLeuValIleAspPheArgThrGlyLysAsnThrMa
 GGTGTTATTAAACCTCACTTGGCAAATGGCGAGCTGCAATGGCATOCACGGCACAAGATAGGCAAGGGCATTGGGGGAGATGGC^{TC}
 ▶ IAIleValLeuPheAsnLeuThrLeuProAsnGlyGlyUserProValProMetAlaSerThrAlaGlyAsnSerGlyGlyAlaPheValGlyAspValValG
 AAGGTGGTGTGCTTTCGCTAAACTACCCAGCAAAGCCAGTTAACGCTCAATGGGTGAGCGAGAAAGCGAACATGCCGTTCAA
 ▶ IAIglyValLeuPheAlaAsnLysLeuThrGlyProLysGlyUserLeuIleValLysTrpGlyGlyUserGlyUserGlyCysArgPheGly

TATCAAGTTGATAATGGATAACGCAAAATACAAAGTCAGGATATTCAATGCCAAAACGCCAAATAATAATTGAAAGAGGATTATGCCAAAA
 ▶ TyrGlyValAspLeuAspAsnAlaGlyIleGlyUserHiSAspIleGlyUserCysLysThrAlaLys
 COCAAAATTAACGOGCTTTOCATCAAAATCCACTGGCTACTTGTAGTGGAGCAAATTAGTGGCTCAAATGCTT
 ▶ ProLysLysLeuThrAlaLeuPheHiS GlynLySerThrAlaThrCysSerGlyAlaAsnTyrSerGlyAlaAsnTyrSerGlyUserLysCysPh
 TAGGTTTCATCGCTGGCTCTGCTTGCTGCTTGCTTGTGCAATTGCGACTGCCCTTATGCTTACGATGGCAGAGTGA
 ▶ eArgPheHiSArgLeuAlaLeuLeuAlaCysValAlaLeuLeuAspCysIleValAlaLeuProAlaTyrAlaTyrAspGlyArgValThrPheG
 AAGGGGAGATTAACTGATGCCACTTGTAAATTGAAACAGACAGCAGGAAATGCCACGGTTACGCA
 ▶ IAIglyUserLeuSerAspGlyUserCysLysIleGlyUserLeuProThrValGlyLysAlaAsnLeuSer
 CACCGAGGGCAAACCGCGCCCTGTCGCTTCCATCACGTTAAAGAATGCCAIGCAGATGATGCTATGAAAGCTAATCTGCTATTAAAGC
 ▶ HiSAlaGlyGlyUserThrAlaAlaProValProPheSerIleThrLeuLysGlyCysAsnAlaAspAspAlaMetLysAlaAsnLeuLeuPheLysGly
 GGGAGACAAACACAGGGCAATCTTATCTTCCAATAAGCCAGGCAAGGCAACGTTGGGCAATTGTC
 ▶ yGlyAspAsnThrThrGlyGlyUserSerAsnLysAlaGlyAsnGlyUserGlyUserValAlaAspGly

- 47 -

Table 5 (cont)

TAGGCCACGCCCTATCAAGGTGGACGGCACCGAACGCCAACACGGAAAAAGGCCCCGACACAGGTAAAGCGAAAACGGCACAGTTATTICAACCCCGT
 ▶ I eGlyThr ProIleLysValAspGlyThrGluAlaAsnSerGluLysAlaProAspThrGlyLysAlaGlnAsnGlyThrValIleGlnProArg
 TTTGGCTACTTTGGCTGGTTATTACGOCACAGGTGAAGGCCACCGCAGGGACGTTGAAGOCACGTCAACTTTGAAGTCAGTATAACTAAAATA
 ▶ PheGlyTyrPheGlySerLeuLeuArgHisArg
 TTTATTATCCAGTGAAAAAATGAATAAGAAATGTTATATAATCATTACTTAACCTTATTTAAAGTTACTACTTTACTATTTACTCTTCAAGTA
 ▶ MetAsnLysSerTyrIleAsnHisTyrLeuThrLeuPheLysValThrThrLeuLeuPheThrLeuSerSerA
 ATCCITGATGGCAAATATAAAACAGTTCAAGGGACAACTAGTGGTTTTOCACTTCTAACAAAGAACTTTCAACATTTATGGCAATTGCAATGG
 ▶ snProValTrpAlaAsnIleLysThrValGlnGlyThrThrSerGlyPheProLeuLeuThrArgThrPheThrPheAsnGlyAsnLeuGlnTrp
 AATGTGAGTGCCTCTAACACCAGCTATATTGTTTCCCTCTAACAGCAAGAGATAATCTTGATACAGTACATATCAATCTCTGAAATTAAATGCTCC
 ▶ AsnValSerAlaLeuGlnProAlaTyrIleValSerSerGlnAlaArgAspAsnLeuAspThrValHisIleGlnSerGluIleAsnAlaPr
 AACAAATTCACTTAGCTCCATTAAATAATTGGATTAATACCAAATCAGCAGTAGAGCTAGGTTATAGCTTGGGGCATTACTTGACTAGTAACTC
 ▶ ▶ ThrAsnSerLeuAlaProPheAsnAsnTrpIleAsnThrLysSerAlaValGluLeuGlyTyrSerPheAlaGlyIleThrCysThrSerAsnP
 CTTGCCAACATGAAATTCATTACCTGATCTACTAAATTAACTCCACCTGAAAGAAAATCTGATGGAGGGAGATTTT
 ▶ ProCysProThrMetLysLeuProLeuLeuPheHisProAspLeuThrAsnLeuThrProProGlyLysAsnSerAspGlyGlyGluIlePhe
 AAATTACATAATGAATCTAAATTAGGOGTCTCTTCAAAATTGGAGTAAAAAGAATACTCTCTAGATGGGTTATGCTAACAGAAATAATTITAG
 ▶ LysLeuHisAsnGluSerAsnLeuGlyValSerPheGlyIleGlyValLysThrAsnThrSerLeuAspTrpValAsnAlaLysAsnAsnPhSe
 CTCTCTAAAGTTTAACTGGCTTTAACTTAGGATAAAATCTTACGCTAAATTTACAGTCAATTACAGTCAATTAAACAGATTTCATCGC
 ▶ ProSerLeuLysValLeuMetValProPheAsnSerSerAspLysIleSerLeuHisLeuArgAlaLysPheHisLeuLeuThrAspPheSerSerL
 TAAATAATGATATTACTATTGACCCATGAAATACTAGTATAGGAAAATTAACTTGAAACGTTGGCGTGGCTAACAGGAAATTTCATGTTAA
 ▶ LeuAsnAsnAspIleThrIleAspProMetAsnThrSerIleGlyLysIleAsnLeuGluThrTrpArgGlySerThrGlyAsnPheSerValLys
 TATGTAGGTGAGGATAAGGGAGATATCTATTCTTTAAATACACCTAAATTCTCTAAACAAACGCGCATGTAACGCTAACATG
 ▶ TyrValGlyIluAspLysGlyAspIleSerIlePhePheAsnThrProLysIleLeuLysGluGlyIluArgArgCysThrLeuAsnAsnAI
 TCCAGTGAGGCCAAATCCAGTTAAATTACGCGGTTAAAAACCTGAATTGGACGCCACAAAGTGAATGGAGGTGGGACATTTCAGTTAACAGAG
 ▶ ProValSerProAsnProValLysLeuArgAlaValLysLysArgGluLeuGluAlaGlnSerGluMetGluGlyIluGlyThrPheGlyIleLeuArgV
 TAAATTGTGACAATACCATAATAAAAGCCAAAGGCAATGGTTATTCTGTAGTGAAAGTTACTTTACGGACGAAAGATGGTACAACGAAT
 ▶ AlaAsnCysAspAsnThrThrTyrAsnLysAlaAsnGlyLysTrpLeuPheProValValLysValThrPheThrAspGlyuAspGlyThrThrAsn
 AATGGAAACAAATGACTTACTCGCACCCAAACAGGCAGGGACAAGGCCACAGGGTTAGCTAACAGAGAAAATGGTACAGAAACG
 ▶ AsnGlyThrAsnAspLeuLeuArgThrGlnThrGlySerGlyGlnAlaThrGlyValSerLeuArgIleLysArgGluAsnGlyThrGluThrVa
 AAAATAACGGTGCTGATCTGCTCAAATGGGGATGCTGGACAATTGAAATTGAAACCACTCCCTGCTGGGAGATCAATATGCTGAAAG
 ▶ IlysTyrGlyAlaAspSerAlaGlnMetGlyAsnAlaGlyGluPheGluLeuArgLysGluProSerProAlaGlyAspGlyNtyrAlaGluUG
 AAACCTTCAAAAGCTATTAGTAAAGACTCAACAAGAGGCCACCTTAATGAAAGGAAAGTCAAAGCOGCGGCCACTTTCACAATGTCATATVAA
 ▶ IuThrPheLysValTyrTyrValLysAspSerThrArgGlyThrLeuIleGlyLysValLysAlaAlaAlaIleThrPheThrMetSerTyrGln

 TAATAATGTCGGGTGGGAATATAAAGGCTGAAGGTTAAACTTCAGTCCTTTTATAGGAAAATACCATTCGAACCTTAAGGATAAAAATTITAT
 CCTAACGACAATTTTATAAGAATAGGTCAAATTATGTTAGGCCAAAGAAAATATAGAAAAGATTACAAACACCAGATTTCACGGTCACAGACA
 ▶ MetLeuAlaLysAlaIaLysTyrArgLysAspTyrLysGluProAspPheThrValThrAspI
 TTATTTAGATTTCAACTTGATCTAAAAATACTGTGGTGAATGCAACCCACAAAATTCCAACGCTTAAATAATGAAGCGACGCTTTACGT. TA
 ▶ IeTyrLeuAspPheGlyLeuAspProLysAsnThrValValThrAlaThrThrLysPheGlyArgLeuAsnAsnGluAlaThrSerLeuArgLeu
 GACGGGCATAGCTCCAGTTCTCTATTAAATTAAATGGGAGOCATTCTGATTATCAACAGATGGCAGAGTTAACGCTGATTTAA
 ▶ AspGlyHisSerPheGlyPheSerSerIleLysPheAsnGlyGluProPheSerAspTyrGlyGluAspGlyIluSerLeuThrLeuAspLeuLys
 AGACAAAAGTGGGGATGAAATTGAGCTTGAAATTGAGCTTCCCTGTCGCGACGGAAAATACGTCATTACAGGGCTATATCAGTCGGGAGAG
 ▶ sAspLysSerAlaAspGlyuPheGlyLeuGluIleValThrPheLeuValProAlaGluAsnThrSerLeuGlyLeuTyrGlyIluSerGlyGluUG
 GTATTTGTACGCAATGTGAGCGGGAAAGGTTTCCGTCAAATCACTTATATGCTGATGCTGCTGTCGCGGTTATATAATCAAAATTACG
 ▶ IlysTyeCysThrGlyCysGluAlaGluGlyIluPheArgGlyIleThrTyrMetLeuAspArgProAspValLeuAlaArgTyrIleLysIleThr
 CGAGATAAAACCAAAATACOCCATTCTCTACTGTCGAATGCTGATGCTGCGGAAATTAGAAGATGTCGCGGAGATTCGGTGGAAATGGAATG
 ▶ AlAspLysThrLysTyrProPheLeuLeuSerAsnGlyAsnArgIleAlaSerGlyGluLeuGlyAspGlyArgHiuTrpValGluTrpAsnAs
 TOCTTTOCCAAAACCAAGCTATTATGCTTACTGTCGCGGAGATNNGGTTATTACAAGATAANTTATTACTAAAAGTGGTGTGAAGTGG
 ▶ pProPheProLysProSerTyrLeuPheAlaLeuValAlaGlyAsp???GlyLeuLeuGlyAsp???PheIleThrLysSerGlyArgGlyuValA
 CTTGTAGAGCTTATGTCGAGCCGCTAACTTAAACCGTGCACACTGGGCCATGCAAAGTCTGAAAAAGGATGAAATGGGATGAAGATGCGTT
 ▶ IaLeuGluLeuTyrValAspArgGlyAsnLeuAsnArgAlaThrGlyAlaMetGluSerLeuLysAlaMetLysTrpAspGlyuAspArgPhe

 ATTITAGAATTTACCTAGATATTATGATCGCGGCCCGGATTCCTCCAATATGGGGCAATGGAAAATAAGGATTAATATCTTTAAC
 ▶ IleLeuGluPheTyrLeuAspIleTyrMetIleAlaAlaAspSerSerAsnMetGlyAlaMetGluAsnLysGlyLeuAsnIlePheAsnSe
 TAAATTGGTGTGGCAAATCCACAAACGGCAACAGATGAAAGATTATCTGTCATGCAAAGTGTGATTGCAACAGAATATCCATAACTGGAGCG
 ▶ PheLysLeuValLeuAlaAsnProGlyNThrAlaThrAspGlyuAspTyrLeuValIleGluSerValIleAlaAlaHiGluTyrSerHiuAsnTrpThrG

 GAAACCGTGTAAACCGCGGAGATGGGTCACACTAGGTTGAAGAAGGTTAACGGCTTGGGACAACAGATTCTCAGATCAGTTCTCGGGGTTGG
 ▶ GlyAsnArgValThrArgArgAspGlyPheAsn

 AACCGATTAAAGGGAAAATTTCGG

-48-

CLAIMS

1. An isolated DNA sequence selected from the group consisting of:
 - (i) an isolated DNA sequence comprising the nontypable *Haemophilus influenzae* serotype 1 LKP operon selected from the group consisting of:
 - a) SEQ ID NO: 4;
 - b) the complementary strand of SEQ ID NO: 4; and
 - c) DNA sequences that hybridize to SEQ ID NO: 4;
 - (ii) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipP* gene selected from the group consisting of:
 - a) nucleotides 1882 to 2532 of SEQ ID NO: 4;
 - b) the complementary strand of a); and
 - c) DNA sequences that hybridize to a);
 - (iii) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipC* gene selected from the group consisting of:
 - a) nucleotides 2854 to 3636 of SEQ ID NO: 4;
 - b) the complementary strand of a); and
 - c) DNA sequences that hybridize to a);
 - (iv) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipR* gene selected from the group consisting of:
 - a) nucleotides 4016 to 6238 of SEQ ID NO: 4;
 - b) the complementary strand of a); and
 - c) DNA sequences that hybridize to a);
 - (v) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipM* gene selected from the group consisting of:
 - a) nucleotides 6259 to 6873 of SEQ ID NO: 4;
 - b) the complementary strand of a); and

- 49 -

- c) DNA sequences that hybridize to a);
 - (vi) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipA* gene selected from the group consisting of:
 - 5 a) nucleotides 6955 to 8365 of SEQ ID NO: 4;
 - b) the complementary strand of a); and
 - c) DNA sequences that hybridize to a); and
 - (vii) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP tip adhesin comprising nucleotides 6955 to 8265 of SEQ ID NO: 4.
2. An isolated *Haemophilus influenzae* protein, selected from the group consisting of:
 - (a) a serotype 1 LKP pilin protein, having the amino acid sequence comprising SEQ ID NO: 5;
 - 15 (b) a serotype 1 LKP periplasmic chaperone protein having the amino acid sequence comprising SEQ ID NO: 6;
 - (c) a serotype 1 LKP membrane anchor protein having the amino acid sequence comprising SEQ ID NO: 7;
 - 20 (d) a serotype 1 LKP tip associated protein having the amino acid sequence comprising SEQ ID NO: 8;
 - (e) a serotype 1 LKP tip adhesin protein having the amino acid sequence comprising SEQ ID NO: 9; or
 - 25 (f) a serotype 5 LKP pilin protein having the amino acid sequence comprising SEQ ID NO: 3; or biologically active fragments thereof.
3. A recombinant *Haemophilus influenzae* LKP tip adhesin fusion protein comprising a biologically fragment of the LKP tip adhesin protein and maltose binding protein or glutathione-S-transferase.

-50-

4. A recombinant *Haemophilus influenzae* serotype 1 LKP tip adhesin fusion protein having the amino acid sequence comprising SEQ ID NO: 11, or a biologically active fragment thereof.
5. A method of producing an antibody which binds to *Haemophilus influenzae* LKP tip adhesin comprising immunizing a mammal with a recombinant *Haemophilus influenzae* LKP tip adhesin fusion protein.
6. A recombinant expression vector comprising a DNA insert encoding a *Haemophilus influenzae* LKP pilus, said expression vector capable of expressing a biologically active LKP pilus in a procaryotic or eucaryotic cell.
10
7. A procaryotic or eucaryotic host cell transformed with an expression vector comprising a DNA insert encoding a *Haemophilus influenzae* LKP pilus, said expression vector capable of expressing a biologically active LKP pilus in the host cell.
15
8. A method of producing *Haemophilus influenzae* serotype 10, serotype 11 or serotype 12 LKP pilus in a procaryotic or eucaryotic host cell comprising the steps of:
20
- a) inserting a DNA sequence encoding a serotype 10, serotype 11 or serotype 12 LKP pilus into an expression vector capable of expressing a biologically active LKP pilus in the host cell, thereby producing a LKP pilus expression vector; and
25
- b) transfecting an appropriate host cell with the expression vector produced in step a) and maintaining the transfected host cell under
30

-51-

conditions suitable for the expression of a LKP pilus in the host cell.

9. A DNA probe capable of hybridizing to a DNA sequence encoding the *Haemophilus influenzae* tip adhesin protein comprising nucleotides between about 6955 to 8265 of SEQ ID NO: 4.
- 5 10. A recombinant DNA molecule which encodes a *Haemophilus influenzae* tip adhesin protein or active fragment thereof.
- 10 11. A method of assaying for the presence of *Haemophilus influenzae* in a biological sample comprising the steps of contacting the sample with a DNA probe comprising about 400 nucleotides capable of hybridizing to a DNA sequence encoding a tip adhesin protein under conditions suitable for hybridization and detecting the presence of hybridized DNA.
- 15 12. A method of vaccinating a mammal against *Haemophilus influenzae* comprising administering to the mammal an effective amount of *Haemophilus influenzae* LKP tip adhesin protein, or a biologically active fragment thereof.
- 20 13. A method of protecting mammals against infections caused by *Haemophilus influenzae* comprising administering to the mammal an effective amount of a composition comprising *Haemophilus influenzae* LKP tip adhesin protein, or a biologically active fragment thereof, and a pharmaceutically acceptable carrier.
- 25

-52-

14. A vaccine composition for protecting mammals against infections caused by *Haemophilus influenzae* comprising a pharmaceutically acceptable carrier and *Haemophilus influenzae* LKP tip adhesin protein, or a biologically active fragment thereof.

5

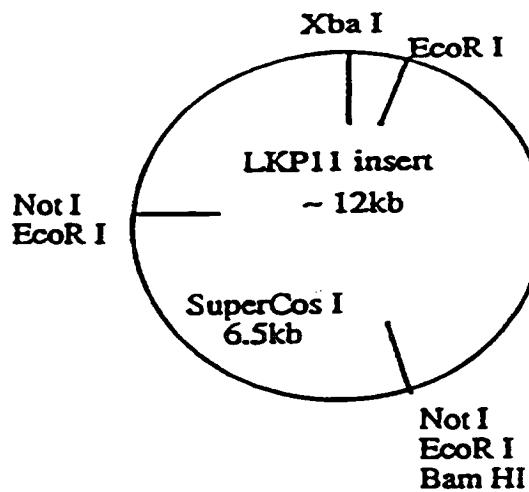
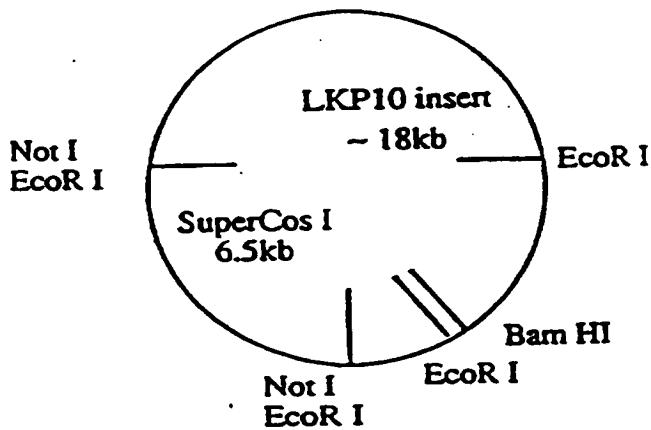
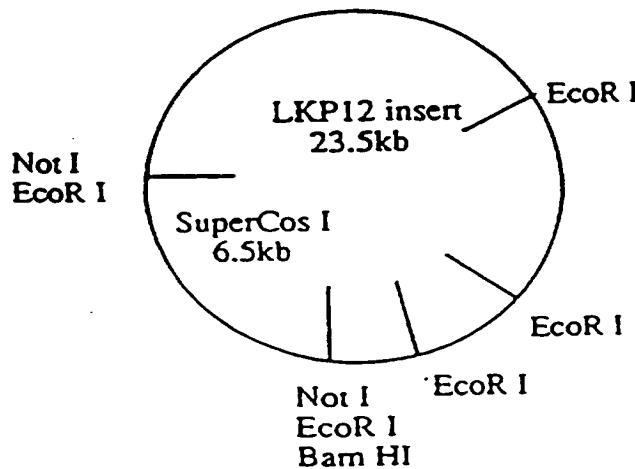
1/5

| | | | | | | | | | | | | | |
|-----------|--------------|-------------|-------------|--------------------|-------------|---------------|-------------|---------|-----|-----|-----|-----|-----|
| LKP1 hifa | MKKTTTGSLI | LLAFATNAAD | PQVSTETSGK | VTFFGKVVEN | TCKVKTDTSKN | MSSVVLNDVGK | NHLKTKKDTA | * | * | * | * | * | * |
| LKP4 hifa | 10 | 20 | 130 | 40 | 150 | 60 | - | - | - | - | - | - | - |
| LKP4 hifa | ...LL... | ...G.VQA | -DIN... | ... | EH.. | L... | ... | ... | ... | ... | ... | ... | ... |
| LKP5 hifa | 10 | 20 | 30 | 40 | 50 | 60 | - | - | - | - | - | - | - |
| LKP5 hifa | ...LL... | ...G.VQA | ADPNP..K... | Y... | SGNRD | A..SQ.GY... | ... | ... | ... | ... | ... | ... | ... |
| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 140 | 140 | 140 | 140 | 140 | 140 |
| LKP1 hifa | MPTPFTINLE | NCSTTTTNN | KPVATKVAY | FYSWRNADEN | NEYTLKNTKS | GNDAAQNWN | QTFDANGTDA | * | * | * | * | * | * |
| LKP4 hifa | 70 | 80 | 90 | 100 | 110 | 120 | 130 | - | - | - | - | - | - |
| LKP4 hifa | ...T.Q | ..DP..ANGT | ANR.N...L. | ...V.KE | .NF... | EQT TA.Y.T... | .IMES...K.> | - | - | - | - | - | - |
| LKP5 hifa | 80 | 90 | 100 | 110 | 120 | 130 | - | - | - | - | - | - | - |
| LKP5 hifa | ...T.. | G.NAN.G.-- | ..K.N...V. | ...N...KE | S... | S.LT | T.K.D... | I.QE... | > | - | - | - | - |
| | 150 | 160 | 170 | 180 | 190 | 200 | 210 | 210 | 210 | 210 | 210 | 210 | 210 |
| LKP1 hifa | IEVVGNGTID | FTHSNNTDVA | TOQTUNKHI | SGKATINGEN | NVKLHYIARY | YATAQAEAGK | VESSVDFQIA | * | * | * | * | * | * |
| LKP4 hifa | 140 | 150 | 160 | 170 | 180 | 190 | 200 | 210 | 210 | 210 | 210 | 210 | 210 |
| LKP4 hifa | ...KE.E. | .M.T.N.G. | LN..P.NT.. | ..STQLT.T. | ELP..F.Q. | ...NR.T... | Q... | ... | ... | ... | ... | ... | ... |
| LKP5 hifa | 140 | 150 | 160 | 170 | 180 | 190 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| LKP5 hifa | ...G.ADKTID. | ...K.NGSTDN | SDKP-T... | ..SATAL.NQG DIA... | Q... | GM.S... | GPT... | P... | > | - | - | - | - |
| LKP1 hifa | YE* | | | | | | | | | | | | |
| LKP4 hifa | | | | | | | | | | | | | |
| LKP5 hifa | 210 | * | * | * | * | * | * | * | * | * | * | * | * |

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Figure 1

2 / 5

CLJ11**Fig. 2A****CLJ10****Fig. 2B****CLJ12****Fig. 2C**

3 / 5

KIEEGKLVIWINGDKGYNGLAEVGKKFEKDTGIKVTVEHPDKLEEKFPQVAATGDGPDIIF
WAHDRFGGYAQSGLLAEITPDKAQDKLYPFTWDARVYNGKLIAYPIAVEALSLIYNKDLL
PNPPKTWEIIPALDKELKAKGKSALMFNLQE PYFTWPLIAADGGYAFKYENGKYDKIKDVG
VDNAGAKAGLTFLVDLIKKNKHMNADTDYSIAEAAFNKGETAMTINGPWAWSNIDTSKVN
YGVTVLPTFKGQPSKPFVGVLISAGINAASPNKELAKEFLENYLLTDEGLEAVNKDKPLGA
VALKSYEEELAKDPRIAATMENAQKGEIMPNIQOMSAFWYAVRTAVINAASGRQTVDDEALK
DAQTRITKIEGRTLSSNPVWANIKTOGTTSGFPLLRTFTENGNLOWNSALOPAYIVSSO
ARDNLDTVHIOSSEINAPTNSLAPENNWINTKSAVELGYSFAGITCTSNPCPTMKLPLLFP
OLTNLTTPGKKNSDGEIFKLHNESNLGVSOIGVKNTSLDWVNAKNNFSSLKVLMVPE
NSSKSISLHLRAKEHILLTDSSLNNDITIDPMNTSIGKINLETWRGSTGNFSVKYVGEDKG
DISIFFENTPKIILKKOORRCTLNNAPVSPNPVKLRAVKKRELEAQSEMEGGTFOLRVNCNDN
TTYNKAN

Fig. 3

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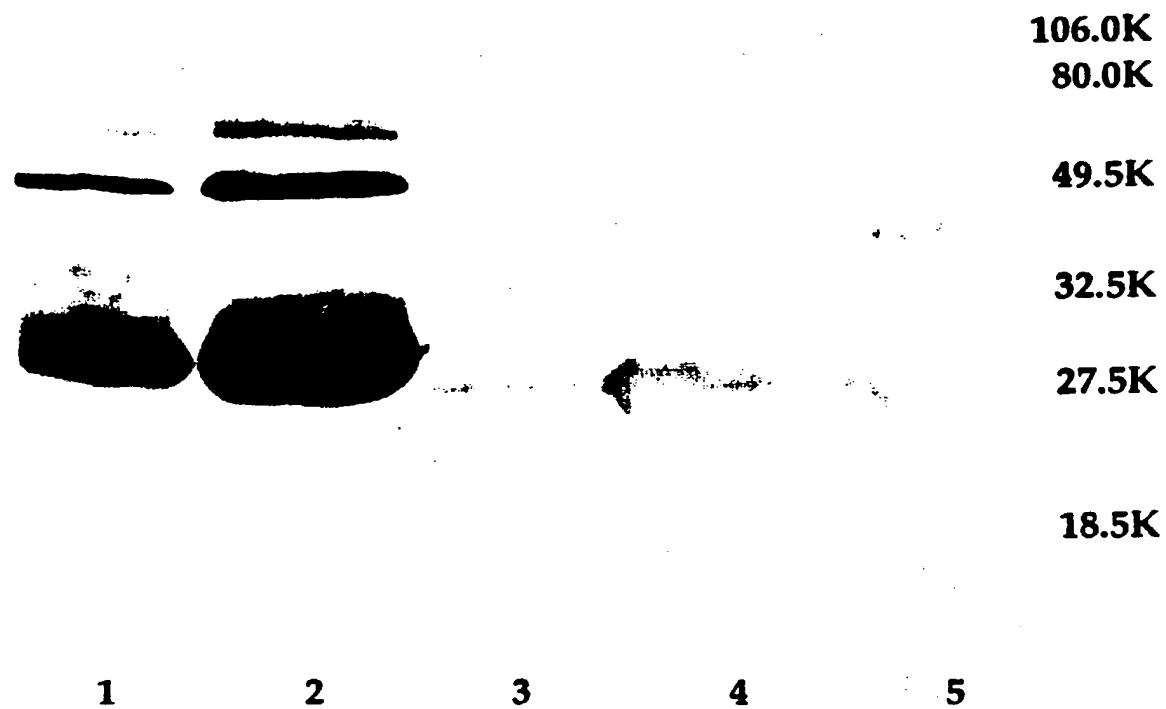


FIG. 4

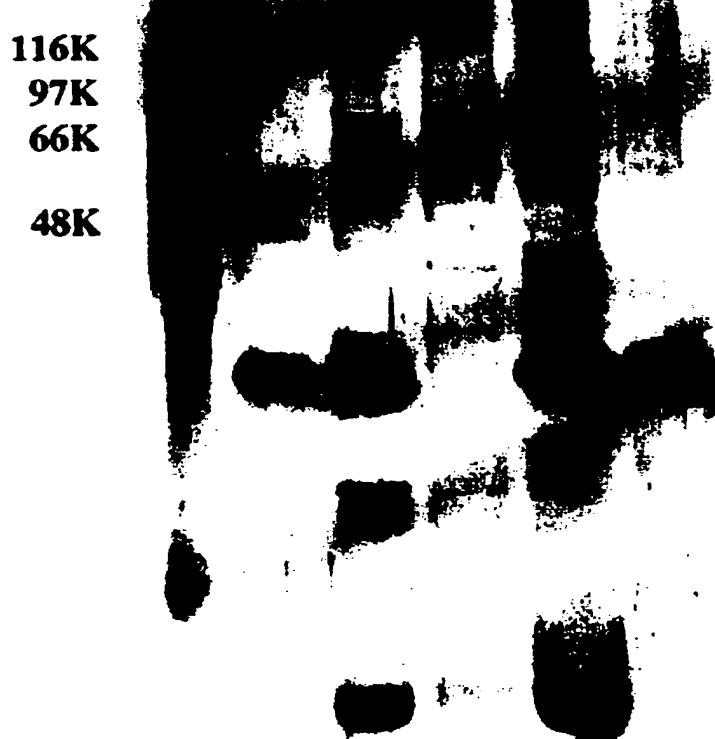


FIG. 5

1 2 3 4 5 6

5/5

FIG. 6

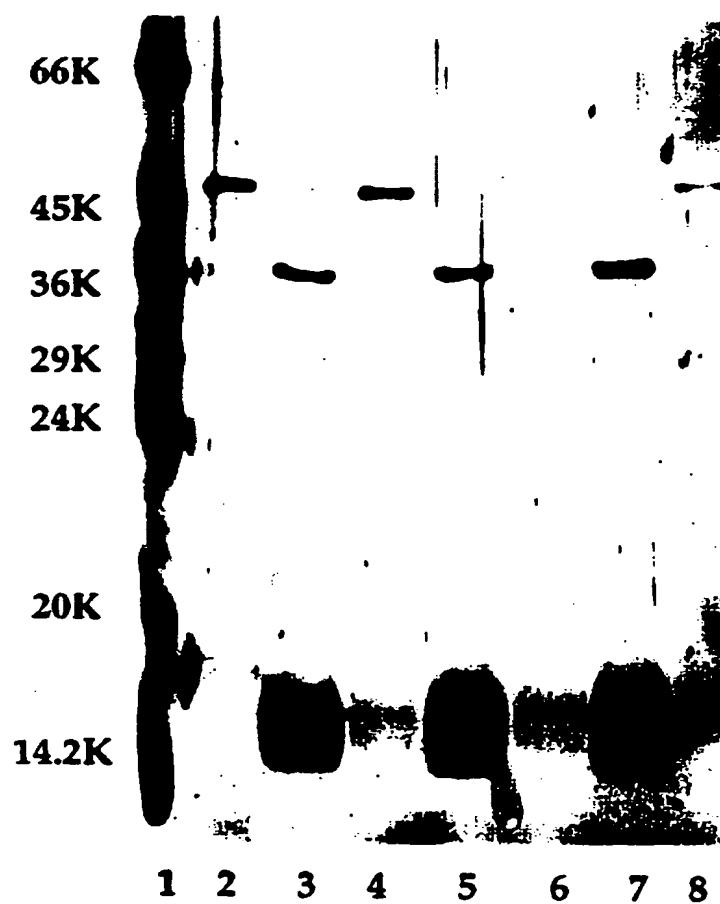
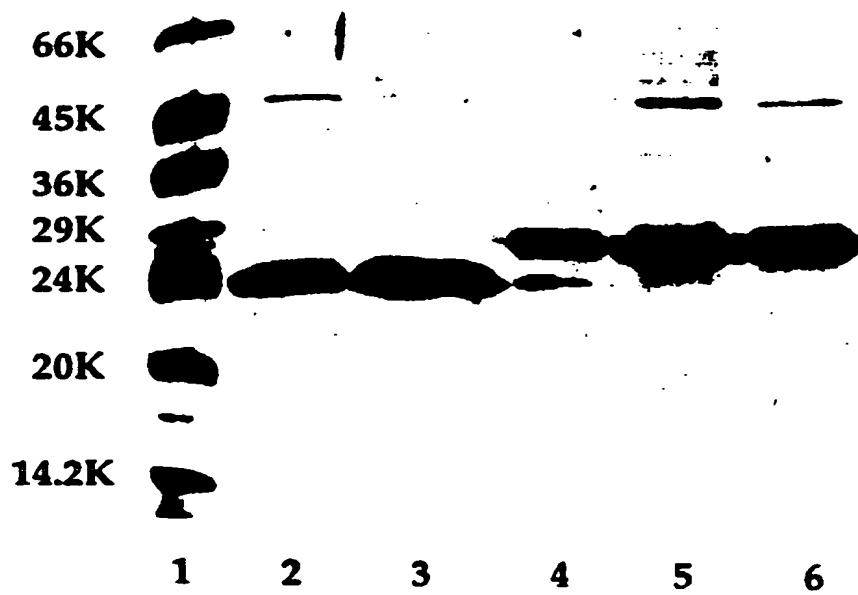


FIG. 7



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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 95/08789

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: C12N 15/31, C07K 14/285, A61K 39/102, C12N 1/21, C12N 5/10, C12Q 1/68
 According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: C12N, A61K, C07K, C12Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EDOC, MEDLINE, BIOSIS, DERWENT BIOTECHNOLOGY ABSTRACT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|---|-----------------------|
| X | WO, A1, 9319090 (BARENKAMP, STEPHEN, J.), 30 Sept 1993 (30.09.93), page 5, line 9 - line 36 -- | 1-11 |
| X | US, A, 5336490 (CHARLES C. BRINTON, JR. ET AL), 9 August 1994 (09.08.94), column 2, line 30 - line 63, claims | 1-8 |
| A | -- | 9-11 |
| X | Database EMBL/GenBank/DDBJ on STRAND, ID=HIIFC, AC=U02932, Watson et al: "Identification of a Gene essential for Piliation in Haemophilus influenzae type b with Homology to the Pilus Assembly Platform Genes of Gram-Negative Bacteria", 1994. -- | 1-2 |

Further documents are listed in the continuation of Box C.

See patent family annex.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 95/08789

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| X | Database EMBL/GenBank/DDBJ on STRAND, ID=HIHIFB, AC=X66606, Smith AL et al: "hif B of <i>H. influenzae</i> is a member of the chaperone family", 1992. -- | 1-2 |
| X | Database EMBL/GenBank/DDBJ on STRAND, ID=HIHIIFA, AC=X16991, van Ham SM et al: "Cloning and expression in <i>Escherichia coli</i> of <i>Haemophilus influenzae</i> fimbrial genes establishes adherence to oropharyn- geal epithelial cells", EMBO J., vol 8, p3535, 1989. -- | 1-12 |
| P,X | Database EMBL/GenBank/DDBJ on STRAND, ID=HII9795, AC=U19795, Green BA et al: "Sequence of LKP serotype 5 hifA gene", 1995. -- ----- | 1-2 |

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 95/08789

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: 12-14
because they relate to subject matter not required to be searched by this Authority, namely:
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Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

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114511

INTERNATIONAL SEARCH REPORT

Information on patent family members.

30/10/95

International application No.

PCT/US 95/08789

| Patent document cited in search report | Publication date | Patent family member(s) | | Publication date |
|--|------------------|-------------------------|---------|------------------|
| WO-A1- 9319090 | 30/09/93 | AU-A- | 3916893 | 21/10/93 |
| | | EP-A- | 0632814 | 11/01/95 |
| | | FI-A,D- | 944273 | 15/11/94 |
| | | JP-T- | 7506248 | 13/07/95 |
| | | NO-A,D- | 943431 | 10/11/94 |
| US-A- 5336490 | 09/08/94 | AU-A- | 3772389 | 12/01/90 |
| | | WO-A- | 8912460 | 28/12/89 |



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|--|---|----------------|---|
| (51) International Patent Classification 6 : C12N 15/31, C07K 14/285, A61K 39/102, C12N 1/21, 5/10, C12Q 1/68 | | A1 | (11) International Publication Number: WO 96/02648 (43) International Publication Date: 1 February 1996 (01.02.96) |
| (21) International Application Number: | PCT/US95/08789 | | (72) Inventors; and |
| (22) International Filing Date: | 13 July 1995 (13.07.95) | | (75) Inventors/Applicants (for US only): GREEN, Bruce, A. [US/US]; 40 Northfield Gate, Pittsford, NY 14534 (US). BRINTON, Charles, C., Jr. [US/US]; 4913 Simmons Drive, Export, PA 15632 (US). |
| (30) Priority Data: | 19 July 1994 (19.07.94) 7 June 1995 (07.06.95) 7 June 1995 (07.06.95) | US US US | (74) Agents: CARROLL, Alice, O. et al.; Hamilton, Brook, Smith & Reynolds, Two Militia Drive, Lexington, MA 02173 (US). |
| (60) Parent Applications or Grants | | | (81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG). |
| (63) Related by Continuation | | | Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i> |
| US Filed on | 08/277,231 (CIP) 19 July 1994 (19.07.94) | | |
| US Filed on | 08/473,750 (CIP) 7 June 1995 (07.06.95) | | |
| US Filed on | 08/477,326 (CIP) 7 June 1995 (07.06.95) | | |
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(54) Title: LKP PILIN STRUCTURAL GENES AND OPERON OF NONTYPABLE HAEMOPHILUS INFLUENZAE

(57) Abstract

The invention relates to the isolation and cloning of the structural gene, *hipP*, for the NTHi pili serotype 5 and the LKP operon. The invention relates to DNA molecules capable of hybridizing to the DNA sequences of the *Haemophilus influenzae* genome related to the pili. The invention further relates to a DNA molecule which encodes a pili protein, particularly a tip adhesin protein. The DNA molecules of the invention can be used in a method for assaying a sample, such as a blood sample, for the presence of *Haemophilus influenzae* in the sample. Accordingly, the invention further relates to the use of the DNA molecules as a diagnostic. The invention also relates to a recombinant *Haemophilus influenzae* pili protein, such as a tip adhesin protein. The protein can be employed in a method for immunizing an animal, such as a human, as a therapeutic or diagnostic.

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-1-

LKP PILIN STRUCTURAL GENES AND OPERON OF NONTYPABLE
HAEMOPHILUS INFLUENZAE

Background of the Invention

Nontypable *Haemophilus influenzae* (NTHi) are primarily noninvasive human respiratory tract pathogens. NTHi can reside in the respiratory tract as a commensal or give rise to local infections, including otitis media,
5 bronchitis, sinusitis, and rarely, pneumonia (Bluestone, C.D., and J.O. Klein, *In Pediatric Otolaryngology.*, 356 (1983); Bluestone and Stool ed. W.B. Saunders Co. Philadelphia.; Musher, D.M. et al., *Ann. Intern. Med.* 99:344-350 (1983)). Several potential adherence factors
10 have been described for *Haemophilus influenzae* (both typable and nontypable) adherence to human cells, including four classes of fimbriae/pili and two high molecular weight proteins with similarity to the filamentous hemagglutinin of *Bordetella pertussis* (St.
15 Geme, J.W., et al., *Proc. Natl. Acad. Sci. USA* 90:2875-2879 (1993)). Pili are bacterial surface antigens. They are protein appendages consisting of a helically symmetrical assembly of major protein (pilin) subunits. Some pili can also carry from two to three minor proteins
20 assembled on their tips. One of these proteins, adhesin, carries the active site for pilus adhesion to specific membrane receptors on human and animal cells.

One class of pili/fimbriae has been widely studied, the long thick pili (LKP) family. LKP pili are expressed
25 by both typable and nontypable *H. influenzae* (Hib). The pili in this family have a characteristic morphology, partially shared adhesion specificity and their structural proteins share amino acid sequences. These pili are hemagglutination positive and mediate attachment to human
30 mucosal cells (Brinton, C.C. et al., *Pediatr. Infect. Dis.*

-2-

mucosal cells (Brinton, C.C. et al., *Pediatr. Infect. Dis. J.* 8 Suppl.:54-61 (1989)). Hemagglutination of human erythrocytes is accomplished via binding to the AnWj blood group antigen while binding to epithelial cells involves a 5 sialic acid containing lactosylceramide receptor (van Alphen, L. et al., *Infect. Immun.* 69:4473-4477 (1991)).

The LKP family has been divided into different strain specific serotypes based on reactivity to polyclonal antisera raised against the purified pili. Little cross 10 reactivity among pili serotypes has been observed (Brinton, C.C., et al., *Pediatr. Infect. Dis. J.* 8 Suppl.:54-61 (1989)).

Inhibiting, or blocking, LKP pilus-mediated adhesion by *H. influenzae* to cells can prevent *H. influenzae* 15 diseases. Purified, intact LKP pili have been shown to be vaccine candidates for NTHi otitis media in the chinchilla model, conferring protection against challenge with NTHi strains bearing homologous pili serotype (Karasic, R. et al., *Pediatr. Infect. Dis. J.* 8 (Suppl.): S62-65 (1988)). 20 However, because protection is pilus-specific, for broad protection, a vaccine would be required to be multivalent, including the most frequently occurring serotypes of pili in the natural population of pathogens. LKP pilin structural genes have been cloned and sequenced by several 25 groups (Coleman, T. et al., *Infect. Immun.* 59:1716-1722 (1991); Forney, L.J. et al., *Infect. Immun.* 59:1991-1996 (1991); Kar, S., et al. *Infect. Immun.* 58:903-908 (1990); van Ham, S.M., et al., *EMBO Jour.* 8:3535-3540 (1989)), but only the genes responsible for pili serotypes 1 and 4 have 30 been identified.

Summary of the Invention

The invention relates to the isolation, cloning and sequencing of the pilin gene for the *Haemophilus influenzae* pili serotype 5 (Figure 1), to the sequencing

- 3 -

- of the entire LKP1 operon, which is set forth in Table 5 and to the cloning of the LKP10, LKP11, and LKP12 pili. The present invention also relates to DNA molecules (also referred to herein as DNA sequences or nucleic acid 5 sequences) which encode proteins which comprise the *H. influenzae* LKP, particularly a tip adhesin protein. The present invention also relates to DNA molecules capable of hybridizing to the DNA sequences of the *Haemophilus influenzae* genome related to the pili. The DNA molecules 10 of the present invention can be used in a method for assaying a sample, such as a blood sample, for the presence of *Haemophilus influenzae*. Accordingly, the present invention relates to the use of the DNA molecules as a diagnostic.
- 15 The present invention further relates to recombinant *Haemophilus influenzae* pili proteins, and peptides, specifically a tip adhesin protein. The proteins, or peptides, of the present invention can be used to produce antibodies, both polyclonal and monoclonal, which are 20 reactive with (i.e., bind to) the *H. influenzae* pili proteins, and can be used in diagnostic assays to detect the presence of *Haemophilus influenzae* antibodies, in for example, a blood sample. Such antibodies to also be used as vaccines in methods of passive immunization.
- 25 The proteins and peptides of the present invention can also be employed in methods for immunizing a mammal, such as a human, against *Haemophilus influenzae* infection and, thus, as a vaccine for the prevention of *Haemophilus influenzae* related diseases, for example, otitis media.
- 30 In particular, based on the DNA and amino acid sequences presented herein, an adhesin protein, or peptide, vaccine can be constructed which can induce protecting antibodies to *H. influenzae* in mammals.

-4-

Brief Description of the Drawings

Figure 1 is a graphic illustration of the conserved regions of the pilin genes of *H. influenzae* serotypes 1, 4 and 5 (SEQ ID NOs:1-3, respectively).

5 Figures 2A, 2B, and 2C are schematics of the physical maps obtained by restriction enzyme digestion of vectors containing LKP inserts.

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10 Figure 3 shows the amino acid sequence of LKP1 fusion protein. The underline indicates the partial amino acid sequence of the LKP tip adhesin protein that was fused to maltose-binding protein.

15 Figure 4 is a photograph of a gel showing the identification of LKP1 tip adhesin protein by antibodies reactive with the fusion protein of LKP1 tip adhesin-MBP in Western blotted membranes. Lanes 1 and 2: different preps of purified LKP1 pili with tip protein (47Kd). (A positive reaction was shown between tip protein and the antibody); lane 3: purified LKP10 pili with tip adhesin (47Kd). (The tip protein does not react with the antibody); lane 4: purified LKP11 pili with tip protein (47Kd). (The tip protein does not react with the antibody); lane 5: protein molecular weight markers.

20 Figure 5 is a photograph of a gel showing the binding activity of LKP1 tip adhesin to human red cell (HRC) ghosts. Lane 1: molecular weight markers; lane 2: purified LKP1 pili with tip protein; lane 3: the pili with HRC ghosts after centrifugation. Tip protein band (47Kd) disappeared due to the binding of tip adhesin pili to ghosts pellet; lane 4: HRC ghosts after centrifugation, used as control; lane 5: purified pili without tip protein (treated with 1% SDS) was incubated with fresh ghosts, showing the same protein band pattern as the pattern of lane 3; Lane 6: purified pili without tip protein. Prior to the gel loading, pili were treated with 1% SDS, 35 exhaustively dialyzed in 25 mM Tris buffer, pH 8.0,

-5-

crystallized by PEG plus NaCl and resolubilized in 25 mM Tris buffer, pH 8.0.

Figure 6 is a photograph of a gel showing the binding activity of purified LKP1 tip adhesin protein to human red cell ghosts. Lane 1: molecular weight markers; lane 2: purified tip adhesin protein with a molecular weight of 47Kd and the protein was removed by 0.1% SDS in 100 mM Glycine buffer, pH 2.0; lane 3: purified adhesin was incubated with fresh human red cell ghosts and pelleted by centrifugation prior to loading the supernatant on the gel. The tip adhesin band disappeared due to the binding to HRC ghosts; lane 4: purified adhesin was incubated with boiled HRC ghosts and pelleted by centrifugation prior to loading the supernatant on the gel. It showed adhesin band with 47Kd, which indicates that tip adhesin protein does not bind to the ghosts pellet; lane 5: supernatant of fresh ghosts after centrifugation. It was used as a control; lane 6: supernatant of boiled HRC ghosts after centrifugation, showing a different soluble protein pattern from that of fresh HRC ghosts, used as another control; lane 7: different prep of purified tip protein incubated with fresh HRC ghosts, which showed the binding between tip protein and fresh HRC ghosts pellet; lane 8: different prep of purified tip protein incubated with boiled HRC ghosts, indicating that the tip protein does not bind the denatured ghosts. The gel was silver stained.

Figure 7 is a photograph of a gel showing adhesin proteins from different LKP type pili with the same molecular weight. Lane 1: molecular weight markers; lane 2: LKP10 pili; lane 3: LKP11 pili and lane 4 to 6: different purified preparation of LKP1 pili. Proteins were stained with silver.

-6-

Detailed Description of the Invention

Described herein, for the first time, is the cloning of the *Haemophilus influenzae* serotype 5 pilin gene and the sequence of the entire LKP1 operon (SEQ ID NO: 4) and 5 the deduced amino acid sequences for six open reading frames (SEQ ID NOS: 5-10). The LKP1 operon, as shown in Table 5, is composed of five separate genes, designated *hipP* (the pilin gene), *hipC* (the periplasmic chaperone gene), *hipR* (the membrane anchor gene), *hipM* (the minor 10 tip associated protein gene) and *hipA* (the tip adhesin gene). These five genes are also referred to herein as *hifA* (for *hipP*), *hifB* (for *hipC*), *hifC* (for *hipR*), *hifD* (for *hipM*) and *hifE* (for *hipA*). Also present on the LKP1 15 operon are an integrase gene, and a peptidase gene. The proteins encoded by these genes of the LKP1 operon and the LKP5 pilin protein are collectively referred to herein as the *H. influenzae* pili proteins.

The present invention encompasses the isolated and/or recombinant nucleic acid sequences encoding the *H. influenzae* pili proteins, or biologically active fragments thereof, described herein. As used herein nucleic acids 20 are also referred to as DNA and RNA, or DNA sequences and RNA sequences, or DNA molecules or RNA molecules. Nucleic acids referred to herein as "isolated" are nucleic acids separated away from the nucleic acids of the genomic DNA 25 or cellular RNA of their source of origin (e.g., as it exists in cells or in a mixture of nucleic acids such as a library), and may have undergone further processing. "Isolated" nucleic acids include nucleic acids obtained by methods known to those of skill in the art to obtain 30 isolated nucleic acids and methods described herein. These isolated nucleic acids include essentially pure nucleic acids, nucleic acids produced by chemical synthesis, by combinations of biological and chemical 35 methods, and recombinant nucleic acids which are isolated.

- 7 -

Nucleic acids referred to herein as "recombinant" are nucleic acids which have been produced by recombinant DNA methodology, including those nucleic acids that are generated by procedures which rely upon a method of 5 artificial recombination, such as the polymerase chain reaction (PCR) and/or cloning into a vector using restriction enzymes. "Recombinant" nucleic acids are also those that result from recombination events that occur through the natural mechanisms of cells, but are selected 10 for after the introduction to the cells of nucleic acids designed to allow and make probable a desired recombination event.

Also encompassed by the present invention are nucleic acid sequences (DNA or RNA sequences) which are 15 substantially complementary to the *H. influenzae* DNA sequences described herein, and nucleic acid sequences which hybridize with these DNA sequences under conditions of stringency known to those of skill in the art sufficient to identify DNA sequences with substantial 20 nucleic acid sequence identity. It is reasonable to predict that DNA sequences identified under such stringent conditions will likely encode a protein (also referenced to herein as a polypeptide, or peptide fragment) with the biological activity of *H. influenzae* pili proteins. A 25 general description of stringent hybridization conditions are discussed in Ausubel, F.M., et al., Current Protocols in Molecular Biology, Greene Publishing Assoc. and Wiley-Interscience 1989, the teachings of which are incorporated herein by reference. Factors such as probe length, base 30 composition, percent mismatch between the hybridizing sequences, temperature and ionic strength influence the stability of nucleic acid hybrids. Thus, stringency conditions sufficient to identify additional *H. influenzae* 35 pili proteins, (e.g., high or moderate stringency conditions) can be determined empirically, depending in

-8-

part upon the characteristics of the known DNA to which other unknown nucleic acids are being compared for sequence similarity.

As defined herein, substantially complementary means 5 that the sequence need not reflect the exact sequence of e.g., SEQ ID NO:4, but must be sufficiently similar in identity of sequence to hybridize with SEQ ID NO:4 under stringent conditions. For example, non-complementary bases, or longer or shorter sequences can be interspersed 10 in sequences provided the sequence has sufficient complementary bases with, e.g., SEQ ID NO:4 to hybridize therewith.

The DNA molecules of the present invention can, preferably, encode a functional or biologically active 15 pili protein, such as the pilin gene, *hipP*; the periplasmic chaperon, *hipC*; the membrane anchor protein, *hipR*; the tip associated protein, *hipM* and most preferably, the tip adhesin protein, *hipA*. A "functional or biologically active protein" is defined herein as a 20 protein which shares significant identity (e.g., at least about 65%, preferably at least about 80% and most preferably at least about 95%) with the corresponding sequences of the endogenous protein and possesses one or more of the functions thereof. Biological functions of 25 the *H. influenzae* pili proteins include antigenic structural, and adhesion properties. For example, as described in Karasic, R. et al. (Karasic, R. et al., *Pediatr. Infect. Dis. J.* 8 (Suppl.): S62-65 (1988)), the teachings of which are herein incorporated by reference, 30 pili proteins can be shown to adhere to mucosal cells and erythrocytes. Thus, such adhesion properties can be a measure of biological activity. Also described herein, biological activity can include the antigenicity of the protein, or peptide, resulting in the production of 35 antibodies which bind to the pili proteins.

-9-

The *H. influenzae* pili proteins of the present invention are understood to specifically include the proteins of the LKP1 operon and the serotype 5 *hipP* pilin protein, and proteins having amino acid sequences 5 analogous to these sequences. Such proteins are defined herein as *H. influenzae* pili protein analogs, or derivatives. Analogous amino acid sequences are defined herein to mean amino acid sequences with sufficient identity of amino acid sequence with, e.g., LKP1 tip 10 adhesin protein, to possess the biological activity of tip adhesin. The biological activity of tip adhesin can include, for example, the capability of tip adhesin to bind to specific membrane receptors on human and animal 15 cells. For example, an analog polypeptide can be produced with "silent" changes in the amino acid sequence wherein one, or more amino acid residue differs from the amino acid residues of the LKP1 adhesin, yet still possess adhesion activity. Examples of such differences include additions, deletions or substitutions of residues to e.g., 20 SEQ ID NO:9. Also encompassed by the present invention are analogous proteins that exhibit lesser or greater biological activity of the pili proteins of the present invention.

The present invention also encompasses biologically 25 active protein, or biologically active fragments of the *H. influenzae* pili proteins described herein. Such fragments can include only a part of the full-length amino acid sequence of a pili protein yet possess biological activity. Such fragments can be produced by amino- and 30 carboxyl-terminal deletions, as well as internal deletions. Such peptide fragments can be tested for biological activity as described herein. Thus, a functional, or biologically active, protein includes mutants or derivatives of the endogenous protein wherein 35 one or more amino acids have been substituted, deleted or

-10-

added. Also included are active fragments of the protein. The *H. influenzae* pili proteins, as set forth above, include functional or biologically active pili proteins, such as the pilin structural protein, *hipP*; the 5 periplasmic chaperon, *hipC*; the membrane anchor protein, *hipR*; the tip associated protein, *hipM*; and most preferably, the tip adhesion protein, *hipA*.

The present invention further relates to fusion proteins comprising the pili proteins described herein 10 (referred to herein as a first moiety) linked to a second moiety not occurring in the pili protein as found in nature. Thus, the second moiety can be a single amino acid, peptide or polypeptide. The first moiety can be in an N-terminal location, a C-terminal location or internal 15 to the fusion protein. In one embodiment, the fusion protein comprises a pili protein and either a maltose binding protein (MBP) (SEQ ID NO:11) or glutathione-S-transferase (GST).

The DNA sequences of the present invention can also 20 be used in a recombinant construct for the infection, transfection or transformation of a cell *in vitro* or *in vivo* under control of an appropriate promoter for the expression of functional *H. influenzae* pili proteins, as defined herein, in an appropriate host cell. Such 25 recombinant constructs are also referred to herein as expression vectors. For example, a DNA sequence can be functionally ligated to a suitable promoter (e.g., a constitutive or inducible promoter or the endogenous promoter) introduced into a suitable expression vector, 30 such as pUC19, which is then introduced into a suitable host cell. The construct can also include DNA encoding one or more selectable markers (such as neo, gpt, dhfr, ada, pac, hyg and hisd) or DNA encoding one or more different antigens or therapeutic proteins.

-11-

The construct can be introduced by any suitable means, as set forth above, such as by calcium phosphate precipitation, microinjection, electroporation or infection (such as with an infectious retroviral, herpes 5 vaccinia or adenovirus vector). The host cell can be a eucaryotic or procaryotic cell. Suitable cells include bacterial (e.g. *E. coli*) or mammalian cells. Mammalian cells include primary somatic cells, such as, epithelial cells, fibroblasts, keratinocytes, macrophages or T cells, 10 or immortalized cell lines, such as HeLa or HT1080. The recombinant host cell can then be cultured and, optionally, selected, *in vitro* under appropriate conditions resulting in the expression of the protein. Alternatively, the cell can be transplanted or injected 15 into an animal, such as a human, for *in vivo* expression.

In one embodiment, the present invention relates to LKP type pili-producing *E. coli* recombinants. Such recombinants have been constructed from *Haemophilus influenzae*, as described herein. These single serotype 20 recombinants produced pili in large, easily purifiable quantities. They did not phase vary or become recalcitrant upon subculture and could be grown as *E. coli* in liquid medium with good pilus yields. The single serotype pilus preparations grown and purified from them 25 contained pili identical to those on the parent *H. influenzae* (*Hflu*) strains and contained no other *Hflu* antigens. These preparations are easily standardized for purity, identity, concentration and potency for subsequent mixing into a multivalent vaccine and provides an efficient means of producing pilus for vaccine 30 manufacture. As described herein, single-type-producing *E. coli* recombinant vaccine strains have been constructed for LKP10, LKP11 and LKP12 serotypes.

Multiple serotype recombinants containing two operons 35 on separate plasmids have also been constructed. Single

-12-

colonies of these strains simultaneously expressed, in good quantities, two serotypes of pili. However, these strains were unstable in that, during *in vitro* subculture, they tended to rapidly lose pilus expression, perhaps 5 because the plasmids used were incompatible. When the two operons are placed on two compatible plasmids these strains are expected to be more stable. The use of stable, high-producing double-expressing recombinant strains could simply production of proteins suitable for 10 vaccine use by reducing by half the number of vaccine strains required.

Good production, concentration and purification methods for *Hflu* LKP pili of different serotypes have been developed and are described herein. Pili can be purified 15 from *E. coli* recombinant cultures producing *Hflu* pili as described for the purification of pili from *Hflu* culture. Both solid phase and liquid phase fermentation methods have been used. The preferred procedure involves mechanical removal of pili from the harvested bacteria and 20 their separation from the bacterial cells by centrifugation. Pili are concentrated and further purified by alternate cycles of longitudinal aggregation (crystallization) of intact pilus rods with soluble impurities removed by centrifugation of the crystals followed by solubilization 25 of the pilus crystals into free pilus rods with particulate impurities removed by centrifugation. Each stage of the production/purification process was optimized for each pilus serotype. To date, nineteen different LKP serotypes have been purified.

30 Alternative pilus purification methods with analytical and industrial utility have also been developed. Using appropriate solvent and column conditions, intact pili can be purified away from contaminating proteins by HPLC or FPLC on molecular sizing, hydrophobic or ion exchange columns.

-13-

These methods are also capable of scale-up for industrial production.

Purification methods for individual pilus proteins have also been developed starting with intact LKP pili. Hflu 5 LKP pilus structural proteins, as deduced from the multiple sequence alignment of pilus gene sequences with other pilus genes, include pilin, small tip minor and large tip minor proteins. The large tip minor protein is referred to as the "adhesin" because it carries the known 10 LKP pilus adhesion specificity for human red blood cells. However, by analogy with other pilus families, the other two LKP pilus structural proteins may also be adhesins with specificities for as yet unknown human receptors. Both pilins and adhesins of LKP pili have been purified in 15 biologically active form.

The pilins are purified in assembled rod form by removal of the minor tip proteins and separation of rods from minors on molecular sizing columns. In their assembled form, the pilin units retain the antigenic 20 specificity of intact pili which is conferred by the exposed surface determinants of the pilin subunits on the lateral surface of the pilus rod. Pilin rods are expected to be equally as effective multivalent vaccine components as intact pili may have advantage of higher purity and 25 possibly reduced side effects.

The adhesin of LKP11 has been isolated and purified in active and soluble form. Its removal from LKP11 pili eliminates the ability of these pili to bind to human red blood cells. In pure form it can bind to human red blood 30 cell membranes. The adhesin band on SDS gels is labeled by antibodies reactive with fusion protein comprised of a fragment of adhesin and maltose binding protein. Purified LKP pilus adhesins may have utility as vaccine components capable of inducing adhesion-blocking or clearing 35 antibodies. The LKP11 adhesin did not cross-react

-14-

antigenically with the LKP1 adhesin on Western blots. Thus, the SDS/PAGE gel similarity of apparent molecular weights found for 3 different LKP adhesins was not predictive of antigenic similarity in this limited two-
5 serotype test. Free adhesins can be tested for efficacy as otitis media vaccines and for their ability to induce adhesion-blocking antibodies. Antiserum to the fusion protein, which labeled the adhesin band on Western blots, did not block adhesion to red cells.

10 The isolated recombinant proteins of the present invention can be administered to a mammal to protect, or to treat the mammal against *H. influenzae* infection. Isolated recombinant pili protein can be formulated into a vaccine composition, for example, as described in U.S.
15 Patent 5,336,490, the teachings of which are incorporated herein by reference. The protein can also be administered via an infectious construct, preferably a replication incompetent or attenuated viral construct. Alternatively, the protein can be administered via a recombinant host
20 cell (such as, a mammalian cell) which will express the protein *in vivo* or in a pharmaceutically acceptable carrier. In particular, the recombinant LKP1 tip adhesin protein, a biologically active fragment thereof, or a fusion protein, can be used in a vaccine composition to
25 induce the production of antibodies in a mammal. It is reasonable to predict that such antibodies can protect the mammal from *H. influenzae* diseases.

The vaccine composition may be administered in a singel dose or in more than one dose over a period of time
30 to achieve a level of antibody in the blood which is sufficient to confer protection from *H. influenzae* infection.

Suitable pharmaceutical carriers include, but are not limited to water, salt solutions, alcohols, polyethylene
35 glycols, gelatin, carbohydrates such as lactose, amylose

-15-

or starch, magnesium stearate, talc, silicic acid, viscous paraffin, fatty acid esters, hydroxymethylcellulose, polyvinyl pyrrolidone, etc. The pharmaceutical preparations can be sterilized and desired, mixed with 5 auxiliary agents, e.g., lubricants, preservatives, stabilizers, wetting agents, emulsifiers, salts for influencing osmotic pressure, buffers, coloring, and/or aromatic substances and the like which do not deleteriously react with the active compounds. They can 10 also be combined where desired with other active agents, e.g., enzyme inhibitors, to reduce metabolic degradation.

For parenteral application, particularly suitable are injectable, sterile solutions, preferably oily or aqueous solutions, as well as suspensions, emulsions, or implants, 15 including suppositories. Ampoules are convenient unit dosages.

Modes of administration are those known in the art, such as parenteral, oral or intranasal administration or by cellular implantation.

It will be appreciated that the actual effective amounts of the protein in a specific case will vary according to the specific compound being utilized, the particular composition formulated, the mode of administration and the age, weight and condition of the 25 patient, for example. As used herein, an effective amount of protein is an amount of protein which is capable of raising the level of antibody in a mammal to a level sufficient to provide protection from *H. influenzae* infection. Dosages for a particular patient can be 30 determined by one of ordinary skill in the art using conventional considerations, (e.g. by means of an appropriate, conventional pharmacological protocol).

The DNA molecules and proteins of the present invention can be used in *in vitro* diagnostic assays to 35 detect the presence of *H. influenzae* in biological

-16-

samples. In one embodiment, the DNA molecules, or fragments thereof, can be used as probes in an assay for detecting *Haemophilus influenzae* in a sample, such as a blood sample from a mammal, e.g. a human. Such probes can 5 be designed such that they specifically bind to the target sequence (e.g., an *H. influenzae* pili protein).

In one embodiment the DNA probe can comprise the nucleotides of a serotype conserved region of the *H. influenzae* genome, such as the nucleotides encoding a tip 10 adhesin protein. To specifically bind to the target sequence, the probe must be of sufficient length to provide the desired specificity, i.e., to avoid being hybridized to random sequences in the sample. The DNA molecule capable of hybridization preferably contains at 15 least about 400 nucleotides, more preferably at least about 1000 nucleotides, and most preferably at least about 1200 nucleotides. For example, the DNA molecule can comprise at least about 400 nucleotides between about nucleotide 7000 to 7400 of SEQ ID NO:4. The DNA 20 hybridization probe preferably shares at least about around 70% homology or the corresponding sequences of the *Haemophilus influenzae* genome, more preferably at least about 80% and most preferably at least about 90%.

In particular, the DNA molecules of the present 25 invention are capable of hybridizing to serotype conserved regions of the *H. influenzae* genome. A particularly preferred embodiment are DNA molecules that hybridize with the *H. influenzae* region encoding the tip adhesin protein. For example, a DNA molecule can be capable of hybridizing 30 to the gene encoding the tip adhesin protein of serotype 1, preferably the sequence set forth between about nucleotide 6955 to 8265 of SEQ ID NO:4. In one embodiment, the DNA molecule is capable of hybridizing to the genome under stringent conditions, as described 35 herein. The hybridization assay can be performed

-17-

employing known hybridization procedures, such as those described herein. The probe can be, for example, detectably labeled employing known labels in the art, including enzymes, dyes, antibodies and radioactive labels. The probe is preferably immobilized on a solid support (e.g., a membrane).

Alternatively, the DNA molecule can be selected such that it hybridizes to a non-conserved region of the *Haemophilus influenzae* genome. For example, a DNA molecule that hybridizes to the gene encoding the pilin protein can be employed. Such an assay can detect the presence of a particular serotype of *Haemophilus influenzae* in the sample.

A sample which can be subjected to the present assay can be any sample which is suspected of containing or being contaminated with *Haemophilus influenzae*. Examples of such a sample include a blood sample, a nasopharyngeal sample, or an ear aspirate.

The assay can be used, therefore, as a diagnostic for the detection of infection of a subject, such as a mammal (e.g., a human), with *Haemophilus influenzae*. The assay can also be used to detect the presence of contamination of a material with *Haemophilus influenzae*, such as a food, medicament, or biological material.

In another embodiment, the protein can be used in an assay for detecting *Haemophilus influenzae* infection in a sample, such as a blood sample. For example, the pili of a pathogen can be isolated from the sample or recombinantly produced, employing the techniques described herein. One or more of the proteins, or fragments thereof, of the pili can then be sequenced. The sequences can be aligned to and compared with the corresponding protein sequence(s) of SEQ ID NO:4. Homology in excess of 90%, for example, is indicative of presence of the pathogen (i.e., infection) in the sample.

-18-

The pili protein, or a fragment thereof (e.g., a peptide fragment) can also be used in an immunoassay, specifically an ELISA, to detect the presence of antibodies in biological samples (e.g., blood, serum or tissue).

5 Such immunoassay can be readily performed by those of skill in the art using well-established techniques to detect antibody bound to LKP pili protein or peptide fragments.

The pili proteins, or fragments thereof (also referred to herein as peptides, or peptide fragments), can also be used to produce antibodies that are reactive with the pili proteins described herein. The term antibody is intended to encompass both polyclonal and monoclonal antibodies. Polyclonal antibodies can be prepared by 10 immunizing an animal with a preparation of crude or purified pili protein using techniques well-known to those of skill in the art. Pili fusion proteins can also be used for immunization. Monoclonal antibodies can be prepared using 15 techniques known to those of skill in the art. These antibodies can be used in diagnostic assays to detect the presence of *H. influenzae* antibodies in biological samples as described above.

The invention is further specifically illustrated by the following examples.

25 Example 1: Cloning and Sequencing of the LKP 5 hipP gene and the LKP1 Operon

Materials and Methods

Bacterial strains and plasmids

H. influenzae strains P860295, P861249, and P860688 30 which express LKP serotypes 1, 4, and 5 respectively, described previously (Brinton, C.C. et al., *Pediatr. Infect. Dis. J.* 8 Suppl.: 54-61 (1989)) were employed. *E. coli* strains MB392 (Kar, S. et al., *Infect. Immun.* 58:903-

-19-

908 (1990)) and HB101 were used as hosts for recombinant plasmids and strain DH5- α was used for cloning steps involving β -galactosidase α -peptide complementation. *Hflu* were grown in brain heart infusion (Dco Laboratories, 5 Detroit, MI) containing 10 μ g/ml hemin (Sigma Chemical Co., St. Louis, MO) and 2 μ g/ml NAD (Sigma) at 37° C. *E. coli* strains were grown in Luria broth (Miller, J.H., In *Experiments in molecular genetics.*, 203 (1972). Cold Spring Harbor Laboratory. Cold Spring Harbor, NY) at 37°C. 10 Where appropriate, antibiotics were used at the following concentrations: ampicillin (Sigma) 100 μ g/ml, kanamycin (Sigma) 25 μ g/ml, and chloramphenicol (Sigma) 20 μ g/ml.

Construction and properties of plasmid pHF1 which expresses LKP1 pili in *E. coli* as described previously 15 (Kar, S. et al., *Infect. Immun.* 58:903-908 (1990)) were employed. Plasmid pPX551 is a pUC18 derivative containing the 1.9 kb XhoI fragment of pHF1 inserted into the BamHI site. Deletion clones of pHF1 lacking the pepN locus were constructed as described in the text. The LKP4 pilin 20 structural gene was isolated by PCR amplification of P860295 chromosomal DNA using primers with the following sequences: for the 5' end of the gene-
5' GTGCTGGATCCGTTCTCTGCATTACATTAGG 3' (SEQ ID NO:12) and
for the 3' end- 5' TTAGGAATTCGGAAGCGTTTTACTTTTTGG3'
25 (SEQ ID NO:13). The 5' primer included a HindIII restriction site, underlined in the sequence, and the 3' primer included an EcoRI site also shown underlined. The PCR product was cloned into pCR1000 (Invitrogen, Inc., CA) as per manufacturer's directions. The LKP4 structural 30 gene was subcloned by blunting the EcoRI site with Klenow in the presence of all four dNTPs, and cutting with Asp718 I (an Asp718 I site is located in the vector) releasing the fragment. The LKP4 gene was ligated into HindII-Asp718 I cut pPX191 (a derivative of pUC19 with the bla 35 gene replaced by the cat gene from pACYC184 (Chang,

-20-

A.C.Y., and S.N. Cohen, *J. Bacteriol.* 134:1141-1156 (1978)) to form pPX602.

The LKP5 pilin structural gene was isolated by PCR using the following primers: for the 5' end- 5'-
5 AACGAATTCTGCTGTTATTAAGGCTTAG (SEQ ID NO:14) and for the 3' -AGCTGGATCCTGTAGGGTGGCGTAAGCC (SEQ ID NO:15). The PCR product of approximately 1 kb was cloned into pCRII (Invitrogen, Inc., San Diego, CA and subcloned as a blunt ended fragment by Klenow treatment of EcoRI ends generated
10 using the vector's flanking EcoRI sites. The LKP5 pilin gene was subcloned into plasmid pPX191 and orientation determined by restriction analysis. The LKP5 subclone was saved as pPX605.

Cloning of *hipP* genes encoding other LKP serotypes

15 *hipP* loci encoding serotype 4 and serotype 1 LKP genes have been described (Kar, S. et al., *Infect. Immun.* 58:903-908 (1990); van Ham, S.M. et al., *EMBO Jour.* 8:3535-3540 (1989)). To determine the serotype specificity of LKP pili is located within the *hipP* gene, PCR was used
20 to clone the serotypes 4 and 5 pilin genes from an NTHi strains expressing these pili. The PCR product for the LKP4 pilin gene was cloned into pPX191 as described above and is expressed under control of the lac promoter. The *hipP* gene from an LKP5 expressing Hflu strain was isolated
25 by PCR as described and cloned into pPX191 for expression under lac control.

Oligonucleotide synthesis

The synthetic oligonucleotides used as primers for PCR amplification and DNA sequencing were synthesized on an
30 Applied Biosystems (ABI) 380B DNA synthesizer using b-cyanoethyl phosphoramidite chemistry (Sinha, N.D. et al., *Nucleic Acids Research* 12:4539-4557 (1984)).

-21-

Polymerase chain reaction (PCR) amplification

The LKP4 *hipP* and LKP5 *hipP* pilin genes were amplified by PCR from NTHi strains P861249 and P860688 respectively, using standard PCR amplification protocols (Saiki, R.K. et al., *Science* 239:487-491 (1988)).

DNA sequencing

The *hipP* gene contained on plasmid pPX551 and the entire LKP1 operon contained on plasmid pHF1 were sequenced with standard M13 sequencing primers and with overlapping sense and antisense primers. All the DNA sequencing was done on an Applied Biosystems (ABI) 373A DNA Sequencer, utilizing the Tag thermal cycling DyeDeoxy™ Terminator sequencing kit from ABI, part # 901497. The LKP4 and LKP5 serotypes were sequenced directly from the PCR products using the PCR amplification primers and internal synthetic primers based on the LKP1 sequencing study.

SDS-PAGE analysis

Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) was performed in a 70 by 100 mm mini-gel system (Bio-Rad, Richmond, CA) using the method of Laemmli (Laemmli, U.K., *Nature (London)* 227:680-685 (1970)). Samples were reduced with β -mercaptoethanol or DTT in sample preparation buffer and boiled for 5 min. Gels were run at 150 V constant voltage. Separated proteins were detected by staining with Coomassie brilliant blue G-250 (Sigma).

Partial purification of pili

LKP pili were purified according to previously described methods using differential pH solubility (Brinton, C.C., Jr. et al., *Pediatr. Infect. Dis. J.* 8 Suppl.:54-61 (1989)). Briefly, pilated bacteria were

- 22 -

harvested from liquid culture by centrifugation and washed 2X in phosphate buffered saline, pH 7.2. The bacterial pellet was resuspended in 100 mM tris, pH 10.3, containing 150 mM NaCl at a ratio of 4 ml buffer/g wet weight of
5 cells. Pili were sheared off of the cells by blending in an Oster miniblender for three 3 min bursts at 4°C. Bacterial debris was separated by centrifugation and discarded. The supernatant was dialyzed against 50 mM NaAcetate, pH 5.0 overnight to precipitate pili and
10 denature other proteins. The pellet was collected by centrifugation at 15,000 x g at 4°C and dissolved overnight in 50 ml of 0.01 M CAPS buffer, pH 10.4 with gentle rocking. This cycle of acid precipitation and solubilization in basic buffer was repeated two more
15 times. The final acid pellet was then resolubilized in 0.01 M NaPhosphate, pH 10.4 and non soluble material discarded. This soluble fraction was referred to as partially purified pili.

Sequence of the LKP1 operon

20 The LKP1 operon was sequenced as described above and the full sequence is set forth in SEQ ID NO:4. Sequence analysis identified six potential open reading frames (ORFs) in the LKP operon, including the *hipP* (at about nucleotide 1882-2532 of SEQ ID NO:4) and *hipC* (at about nucleotide 25 2854-3630 of SEQ ID NO:4) genes. All six ORFs in the LKP operon were identified as homologous to equivalent pilus operon genes in the pilus superfamily, as defined by multiple sequence alignment of proteins. Analysis of sequence alignment was also performed using Entrez
30 Sequences Database Release 10.0 of the National Center for Biotechnology Information (National Library of Medicine, Bethesda, MD). Derived amino acid sequences of the ORFs are shown in Table 5 (SEQ ID NOS:5-10). A function for each reading frame was assigned based on sequence

-23-

alingment analysis. There are five ORFs which appear to be grouped into an operon controlled by the *hipC* promoter region. After the *hipC* (periplasmic chaperon) gene, the second reading frame *hipR* (at about nucleotide 4016-6238 of SEQ ID NO:4) was designated, a membrane anchor protein, the third ORF *hipM* (at about nucleotide 6259-6873 of SEQ ID NO:4) was designated, a tip associated protein, (also referred to herein as a minor tip protein) and the fourth ORF *hipA* (at about nucleotide 6955-8265 of SEQ ID NO:4).
5
10 was designated, a tip adhesin protein. The pilin gene (*hipP*) and the periplasmic chaperon gene (*hipC*) are transcribed in opposite orientations as in the LKP 4 operon with the promoter region having the previously identified TA repeats (van Ham, S.M. et al., *Cell* 73:1187-1196 (1993)). Since pHF1 expresses LKP1 pili in *E. coli*, there are 10 TA repeats in the intrapromoter region as described by van Ham et al.. These TA repeats are responsible for phase variation of the LKP pili phenotype, with loss of some of the repeats resulting in loss of
15
20 piliation and a TA repeat number between 10 or 11 allowing expression of the LKP operon. As identified on the LKP1 operon was an ORF encoding an integrase (at about nucleotide 1495-1868 of SEQ ID NO:4). Also located on the LKP1 operon was a sequence encoding an enzyme, peptidase
25 (at about nucleotide 8395-9347 of SEQ ID NO:4).

The predicted size of the LKP1 *hipP* gene product is approximately 21.2 kilodaltons, assuming a signal sequence length of 20 amino acids, while the observed molecular weight in SDS-PAGE gels is approximately 27 kilodaltons.
30 Part of this may be explained by the anomalous sequence migration of LKP pilins in general in SDS-PAGE gels (mature LKP4 migrates at a molecular size of 24 kilodaltons while its predicted size is 22.1 kilodaltons) but the exact explanation remains unknown.

-24-

Sequence comparison of LKP serotypes 1, 4, and 5 hipP genes

This report represents the first sequence analysis of the *hipP* genes encoding LKP serotypes 1 and 5 (Figure 1).

5 The *hipP* gene from an LKP4 expressing *Hib* strain has also been sequenced (van Ham, S.M. et al., *EMBO Jour.* 8:3535-3540 (1989)) and the derived amino acid sequence shows 99% identity with the LKP4 *hipP* derived amino acid sequence contained herein. The *hipP* gene sequences from *Hib*

10 strains Eagan and M43 have been published (Forney, L.J. et al., *Infect. Immun.* 59:1991-1996 (1991)). The LKP1 *hipP* gene should encode a protein of approximately 21.5 kD while the predicted molecular weight of the LKP 4 *hipP* protein is 23.8 kD. The actual *hipP* gene products

15 observed in recombinant *E. coli* are of approximately the correct sizes in Western blots for LKP4 and LKP5, but the LKP1 pilin runs aberrantly at a higher molecular weight than predicted at 26 kD. MacVector software was used to assess homology of these genes, with LKP4 *hipP* and LKPS

20 *hipP* proteins being 70 and 67% identical to LKP1 *hipP*, respectively. The alignment between the sequences is very good at the amino termini of the proteins, with three major areas of sequence divergence in the LKP1, 4, and 5 serotype genes farther into the proteins as shown in the

25 Figure. Since little cross reactivity is observed between anti-LKP1, anti-LKP4, or anti-LKP5 sera with intact pili of a heterologous serotype, the sequences responsible for the serotype specificity of the typing antisera must be located in these regions. By comparison of the sequences

30 in GenBank to the LKP4 sequence, the *H. influenzae* type b M43 pilin (Gilsdorf, J.R. et al., *Infect. Immun.* 58:1065-1072 (1990)) sequenced by Gilsdorf et al. also appears to be an LKP4 serotype gene (data not shown).

- 25 -

Example 2: Construction of LKP Type Pili-Producing E. coli Recombinants

Bacterial strains

Piliated *Hflu* strains used for *E. coli* recombinant construction are LKP11/CB59, LKP10/88-0807 and LKP12/88-0677. Hemagglutination and serum agglutination were examined before making genomic library. *E. coli* strains XL1-Blue™ and HB101 were used as cloning host cell.

DNA library construction and cosmid vector DNA

10 Chromosomal DNA from LKP11, LKP10 and LKP12 were extracted and purified respectively by standard techniques. *Hflu* genomic DNA size is about 1.8×10^6 bp. Chromosomal DNA was partially digested with restriction enzyme *Sau3A I*. Approximately 30kb DNA fragment was eluted from LMTA-15 gel (Sigma) and purified by phenol-chloroform method. The final DNA concentration is about 1ug/ μ l.

20 Vector DNA SuperCos I (Stratagene, La Jolla, CA) was digested with *Xba I* and dephosphorylated with calf intestinal alkaline phosphatase (CIAP). The *Xba I* and CIAP treated vector DNA was then digested with *Bam HI* restriction enzyme. About 6.5kb vector DNA fragment was obtained.

25 LKP11/CB59, LKP10/88-0807 and LKP12/88-0677 DNA fragments were ligated at the *Bam HI* site of the vector DNA SuperCos I, respectively. The ligated DNA was packaged into 1 phage particles using Ciga-pack Gold kit (Stratagene, La Jolla, CA). The host cell for packaging was XL1-Blue™.

Library screening

30 Recombinant expressed LKP type pili were screened by colony blot method. The concentration of anti-pilius sera from LKP11, LKP10 and LKP12 was 1:1000 dilution. The percentage of positive colony was 40/4200 for LKP11, 9/700

-26-

for LKP10 and 1/600 for LKP12. The cell pilation was examined by EM. The recombinants were verified by further HA and SA assay and they were named CLJ11 for LKP11, CLJ10 for LKP10 and CLJ12 for LKP12 (Figures 2A, 2B and 2C).

- 5 Recombinants DNA was extracted and transformed to *E. coli* strain HB101 because XL1-Blue cell expresses type I pili. The recombinants DNA size is about 18.5kb for CLJ11. This was obtained by digestion and subsequent ligation using restriction site on insert and vector DNA. CLJ10 DNA is
10 about 25kb and 35kb is for CLJ12. Partial DNA sequence is available for these recombinant inserts.

Example 3: Protocols for the Purification of an LKP Pilus from an *E. coli* Recombinant Strain Using the Liquid Phase Method

- 15 General Protocol
1. Inoculate recombinant *E. coli* cells in a 3 ml of LB media containing ampicillin and grow at 37°C until the OD 540nm reading reaches 0.6-0.8 (3-4 hours).
 2. Transfer the cell suspension to 50 ml of medium and
20 grow at 37°C until the reading at 540 nm reaches 0.8-1.0 (4-5 hours).
 3. Transfer the 50 ml of cell suspension to 1L of medium in 2.8L flask and grow at 37°C overnight (16-18 hours) until a reading at 540 nm of 4.0-5.0 is
25 obtained.
 4. Harvest cells by centrifugation at 5000 rpm for 15 minutes.
 5. Resuspended the cells in 50 nM acetate buffer pH 5.0 and keep the suspension at room temperature for 1
30 hour.
 6. Blend at 11000 rpm in large cup, or 14000 rpm in small cup, with omnimixer, ice for 3 minutes.
 7. Titrate to pH 8.0 with 1 M Tris-HCl and let stand for 3 hours at room temperature.

-27-

8. Centruge at 12000 rpm for 20 minutes at 4°C. Weigh all pellets and discard.
9. Add 10 ul of DNase and RNase for each 100 ml of prep. Mix thoroughly and let stand for 10 minutes at room temperature.
10. Dialyze against several changes of 50 mM acetate buffer pH 5.0 overnight. If the prep does not reach pH 5.0 overnight, then dialyze longer against more changes of buffer.
- 10 11. Centruge at 16000 rpm for 60 minutes at 4°C to pellet the protein precipitant and pilus crystals.
12. Resuspend the pellet in about 25% original volume with 25 mM Tris-HCl buffer pH 8.0.
13. With gentle stirring add Triton X-100 and EDTA to the prep to yield final concentration of 0.2% and 5 mM. Stir gently overnight at 4°C.
14. Clary the prep by centruing at 16000 rpm for 60 minutes at 4°C.
15. Add NaCl and PEG 8000 to final concentration of 0.5 M and 3.0% respectively then incubate and prep over ice for 2 hours.
16. Centruge the prep at 16000 rpm for 60 minutes at 4°C to pellet the pilus crystals.
17. Resuspend pellet in 25 mM Tris-HCl pH 8.0 in 1/3 of previous volume. Use less solution a lesser yield of pilus crystals is obtained.
18. Repeat steps 13 to 17.
19. Resuspend pellet in 25 mM Tris-HCl pH 8.0. Depending on purity and amount of material alternative solubilization and crystallization steps may be continued as needed.
During purification, sample after each step and use SDS-PAGE to examine purity of the samples. Dark field microscopy assay is needed in assistance for purity

-28-

checking. It is necessary to use UV scanning to determine any contamination by DNA or RNA.

Since Triton X-100 has a strong absorbance at 280 nm, it is important to remove the residual of Triton X-100 by 5 crystallization, one time, or more, of pili by PEG and NaCl after purification. This avoids false reading at 280 nm when one determines concentration of pilus preparation by UV method.

Purification of LKP 5 Pili

- 10 1. Harvest in 80 mM PBS pH 5.0 using 5-10 ml/tray.
2. Titrate prep to pH 5.0 with 6N HCl if necessary.
3. Blend with omnimixer over ice for 3 minutes (average speed=9800 rpm) (up to 11000 rpm if possible in larger cups and up to 14000 rpm in small cups).
- 15 4. Titrate to pH 9.0 with 5 M NaOH and let stand for 3 hours at room temperature. It may be necessary to stir gently to prevent pH changes. Monitor pH throughout and adjust if needed. (If cultures were grown in broth, then titrate with a 1 M solution of buffer (Tris) instead of NaOH.)
5. Centrifuge at 15300 g for 20 minutes at 4°C. Transfer supernatant to clean bottles and clarify a second time as before. Weigh all pellets and discard.
- 25 6. Adjust pH of supernatant to 8.0 and add 10 ul of DNase and RNase for each 100 ml of prep. Mix thoroughly and let stand for 10 minutes at room temperature.
7. Dialyze against several changes of 40 mM acetate buffer pH 5.0 overnight. If prep does not reach pH 5.0 overnight then dialyze longer against more changes of buffer.

-29-

8. Centrifuge at 18600 g for 60 minutes at 4°C to pellet the pilus crystals (crystals not typical for clear pili).
9. Resuspend the pellet in about 25% original volume with 25 mM Tris-CHI pH 9.0 using rubber policeman. Stir gently at 4°C (avoid forming) several hours. Break up large pieces with gentle pipeting as needed.
10. With gentle stirring, add Triton X-100 (2% stock) to the prep to yield a final concentration of 0.4% and add EDTA (25 mM stock) to a final concentration of 5 mM. Incubate overnight at 4°C.
11. Clarify the prep by centrifuging at 186000 g for 60 minutes at 4°C. Transfer supernatant to clean flask.
12. Adjust the pH of the supernatant to below 8.0 using 1 N HCl.
13. Add NaCl (5 M stock) to a final concentration of 0.5 M and PEG (30% stock) to final concentration of 3% then incubate the prep over ice for 0.5 hour. Inspect in darkfield for crystals. Increase time if needed but it is critical not to overexpose pili to PAGE because resolubilization becomes increasingly difficult with increasing times.
14. Centrifuge prep at 18600 g for 60 minutes at 4°C to pellet the pilus crystals.
15. Wash pellet with 40 mM citrate buffer pH 5.0 to remove excess PEG/NaCl. Then centrifuge at 186000 g for 60 minutes (2 times).
16. Resuspend pellet in 25 mM Tris-CHI pH 9.0 in 1/3 to 1/2 previous volume. Solubilize by swirling followed by gentle pipetting. Run sample on a gel to check for purity. If necessary, continue with step 17.
17. Add Triton x-100 to the prep to yield a final concentration of 0.4% and add EDTA to a final concentration of 5 mM then incubate overnight at 4°C (see step 10 for details).

-30-

18. Adjust the pH of the prep to below 8.0 using HCl (between 7 and 8).
19. Add NaCl to a final concentration of 0.5 M and PEG to a final concentration of 3% then incubate the prep over ice for 0.5 hours (see step 13 for details).
- 5 20. Centrifuge prep at 186000 g for 60 minutes at 5°C to pellet pilus crystals.
21. Resuspend the pellet in 252 mM Tris-HCl pH 9.0 to solubilize pili (see step 16 for details). Check for 10 purity by SDS-PAGE. If necessary, continue with step 22.
22. Add Triton X-100 to the prep to yield a final concentration of 0.4% and add EDTA to a final concentration of 5 mM then incubate overnight at 4°C 15 (see step 10 for details).
23. Clarify by centrifuging at 18600 g for 60 minutes at 4°C.
24. Add NaCl to a final concentration of 0.5 M and PEG to a final concentration of 3# then incubate the prep 20 over ice for 0.5 hour (see step 13 for details).
25. Centrifuge at 18600 g for 1 hour at 4°C.. Discard supernatant.
26. Resuspend pellet in Tris-HCl pH 9.0. Depending on amount and purity of material, alternating 25 solubilization/crystallization steps may be continued as needed.

During purification process, monitor pellet material and supernatant by darkfield and/or gel and/or scan. May need to reprocess
- 30 Purity by SDS-PAGE check: Repeat Triton step as needed, but avoid SDS reaction steps in previous protocols because of high losses of pili.

-31-

Example 4: Purification of LKP pili by HPLC and other Column Methods

Besides detergent extraction and PEG precipitation, LKP pili also can be purified by HPLC, FPLC and other column methods. These methods are good particularly for unknown LKP pili. Normally, pili are partially purified by extraction and precipitation first until the pilus solution is clear, concentrated and very small size. the preparation still is not pure as determined by SDS-PAGE, column methods would be the application of the choice.

Sizing columns are preferred to be used for this purpose. Prior to loading to a column, treatment for further purification of the pilus sample is important. The detergent used for partial purification of pili should be removed from pilus samples by dialysis or other known techniques. Detergent significantly reduces column separation resolution. Size exclusive column requires a small sample volume.

For HPLC or FPLC, the loading volume of 50 ul to 200 ul is recommended, and for other routine LC gel filtration columns, the sample loading volume depends on the length and size of the column. A 1 ml of pilus sample is preferred for a column with a total volume of 50 ml. Since pili have a low absorbance at 280 nm, a higher sensitivity for monitor is recommended. Available protein eluted from column can be monitored at 230 nm. Further purification of proteins can be performed by HPLC. Column methods of purification are also useful for isolation of pilin from pili.

30 Example:5 Protocol for the Purification of an LKP Pilus from an Hflu Strain or E. coli Recombinant Strain Using Solid Phase Method

Generally speaking, recombinant strain expresses pilus structural protein better than parent strain, H flu,

-32-

- does, therefore, it is easier to purify pili from the recombinant cells. However, due to the fact that the *E. coli* recombinant strain expresses the pilus protein as same as the parent *Hflu* does, purification procedures of
- 5 pilus rods from *Hflu* or from recombinant strain are basically the same. Growth of *Hflu* strain requires chocolate agar media and certain CO₂ and humidity. Growth of *E. coli* recombinant strain needs LB agar media containing ampicillin.
- 10 1. Harvest in 80 mM PBS pH 5.0 using 5 ml/tray. Use a smoothed glass edge to scrape wet cells and then transfer the cell suspension to omnimixer cup. less cells are made surface only use media surface moisture to collect wet cells.
- 15 2. Titrate prep to pH 5.0 with 2 M acetate buffer necessary.
3. Blend at 14000 rpm with omnimixer over ice for 3-5 minutes.
4. Titrate to pH 8.0 with 1 M Tris-HCl buffer and
- 20 monitor pH change by pH meter. It may titrate to pH with 2.5 or 5 M NaOH instead of Tris buffer, prep contains a lot of wet cells. Be careful to avoid lysis of cells when use NaOH. Incubate the prep at room temperature for 3 hours.
- 25 5. Centrufe at 12000 rpm for 20-30 minutes at 4°C. Weigh all pellets and discard.
6. Add 10 ul of DNase and RNase for each 100 ml of prep. Mix thoroughly and let stand for 10 minutes at room temperature.
- 30 7. Dialyze against several changes of 50 mM acetate buffer, pH 5.0, overnight. If the prep does not reach pH 5.0 overnight, then dialyze longer against more changes of buffer.
8. Centrufe at 16000 rpm for 60 minutes at 4°C to pellet protein precipitate and pilus crystals.
- 35

-33-

9. Resuspend pellet in about 25% original volume with 25 mM Tris-HCl buffer, pH 8.0.
10. With gentle stirring, add Triton X-100 and EDTA to prep to yield final concentration of 0.2% and 5 mM.
- 5 Stir gently overnight at 4°C.
11. Clary prep by centrugation at 16000 rpm for 60 minutes at 4°C.
12. Add NaCl and PEG 8000 to final concentration of 0.5 M and 3.0%, respectively, then incubate the prep over
- 10 ice for 2 hours. LKP pili with different length and dimer may be crystallized in different concentrations of NaCl and PEG 8000. Therefore a concentration test for NaCl and PEG to crystalize different pili is important.
- 15 13. Centruge at 16000 rpm for 60 minutes at 4°C to pellet pilus crystals.
14. Resuspend pellet in 25 mM Tris-HCl, pH 8.0 in 1/3 previous. Use even less solution a smaller yield of pilus crystal is found.
- 20 15. Repeat from step 10 to step 14.
16. Resuspend pellet in 25 mM Tris-HCl, pH 8.0. Depending on purity and amount of material, alternate solubilization and crystallization steps may be continued as needed.
- 25 During purication, sample after each step and use SDS-PAGE to examine purity of the samples. Dark field microscopy assay is needed in assistance for purity checking. It is necessary to use UV scanning for finding out any contamination by DNA or RNA.
- 30 Since Triton X-100 has a strong absorbance at 280 nm it is wise to remove the residual of the detergent by one more time crystallization of pili by PEG and NaCl after purication. This avoids false readings at 280 nm when one determines concentration of pilus preparation by UV
- 35 method.

- 34 -

Example 6: Construction of MBP-A3' Tip Fusion Protein

The genetic fusion was constructed by using PCR primers to obtain a portion of the LKP1 tip gene from pHF1 which would be in frame with the MBP protein gene in the 5 vector pMAL-p2. The primers were designed so that the carboxyl terminal of approximately 100 amino acids of the tip protein would be deleted and replaced with a stop codon. The amino terminal portion of the protein was PRC'd in frame with an appropriate restriction site at the 10 approximate point of the signal sequence cleavage site which was determined by analogy to other bacterial signal sequences and the hydrophobicity profile of the deduced amino acid sequence of the tip protein. The amino acid sequence of the fusion protein is shown in Figure 2. The 15 partial sequence of the LKP tip protein of the fusion protein is underlined.

Expression of the fusion, purification, and antisera production

The protein was expressed in *E. coli* BL21 (an 20 *ompT*.*lon* K-12 strain) grown in SOB broth containing ampicillin at 100 µg/ml at 28 C after induction with 0.2 mM IPTG. The cells were pelleted by centrifugation and washed 1 time in PBS. The cells were resuspended in 20 mM Tris, pH 7.5 containing 2 mM EDTA and 400 mM NaCl at a 25 ratio of 20 ml/liter of original culture. The cells were lysed by passing through a French pressure cell 3 times and the cell debris removed by low speed centrifugation at 8 times x g for 20 minutes at 4°C. The supernatant was diluted 5-fold in the same buffer used for breakage and 30 passed over a 15 ml bed volume amylose resin column at 1 ml/min at room temperature. After the lysate was run over the column, the column was washed with 15 bed volumes of the lysing buffer at 5 ml/min. The bound material was eluted using washing buffer containing 10 mM maltose. The

-35-

elution was done with 50 ml of buffer at 1 ml/min and the eluant pooled. The resulting protein mixture was analyzed by SDS-PAGE and Western Blot and anti-MBP sera and found to contain the fusion, breakdown products, and full length MBP. Little other material was detected.

The fusion proteins, MBP and breakdown products eluted as a complex. Mice were immunized with 10 µg doses of the complex using 100 µg MPL as adjuvant. Immunizations were done subcutaneously at weeks 0, 4, and 10 and the mice exsanguinated on week 8. The negative control sera was mouse anti-MBP sera made against purified MBP using the same purification and immunization protocols.

Anti-GST sera

The GST fusion was constructed using the complete LKP tip gene, including the signal sequence. The gene was PCR'd out from PHF1 with the appropriate restriction enzyme sites for insertion into pGEX-3X in frame, and expressed in *E. coli* DH5 α . The cells were grown in SOB containing 100 µg/ml ampicillin and induced with IPTG at 0.2 mM at 37°C for 2 hours. The cells were harvested and washed in PBS, then resuspended in PBS and lysed by passing through a French pressure cell. Cell debris was harvested by centrifugation, and washed 3 times with buffer containing 1% Triton X-Zwittergent 3-14 and the inclusion bodies recovered by centrifugation. The inclusion bodies were solubilized in 5 M guanidine HCl and analyzed by SDS-PAGE. The guanidine concentration was lowered to 2.5 M by dialysis and the soluble inclusion bodies stored at 4°C. The antisera was made by running preparative 10% SDS-PAGE gels and cutting the fusion band out of the gel. The acrylamide-protein band was minced using a scalpel and mixed with MPL (100 µg) and injected into mice 3 times at weeks 0, 4, and 6. Mice were bled at week 8.

-36-

Example 7: Removal, Purification and Identification of H. influenzae LKP Pilus Tip Adhesin Protein

- This is the first demonstration that tip adhesin protein from *H. influenzae* LKP1 pili can be removed without depolymerization of pilus rods. Free tip adhesin protein can be isolated and purified by means of dialysis and prep-electrophoresis. Purified tip adhesin can be identified by the antiserum from a constructed genetic fusion protein, which is from a portion of LKP1 tip gene and MBP (maltose binding protein) gene, using Western blot analysis. Specific binding was detected between the purified tip protein and fusion protein antiserum, which clearly shows that the protein purified from LKP1 pilus prep is LKP1 tip adhesin protein.
- Activity assays with human red blood cell (RBC) ghosts demonstrated that purified tip protein binds to a native ghosts preparation but not does not bind to denatured RBC ghosts, indicating that purified tip protein is biologically functional or at least partially functional.

Removal of Tip Protein from Pilus Rods

1. Dialyze purified LKP1 pili in 200 mM Gly-HCl buffer, pH 2.0 containing 5 M NaCl, at room temperature for 4 to 6 hours.
2. Transfer the dialysis bag into a 25 mM Tris-HCl buffer, pH 8.0 and dialyze for several hours till the pH of pilus prep reaches to pH 8.0.
3. Add SDS to the pilus prep to a final concentration of 0.1% and incubate in 4°C for 10 hours.
4. Dialyze the pilus prep in 50 mM citrate buffer, pH 5.0 overnight.
5. Pilus aggregates can be removed by centrifugation and most free tip protein is retained in the supernatant.

-37-

Tip protein can be completely removed by 2% SDS in 25 mM Tris buffer without depolymerization of pilus rods, but the SDS may damage the activity of the protein. 0.1% SDS only removes about 20-30% of total tip protein, however, 5 the protein maintains biological activity. The results also demonstrated that 4M urea and 2M GuHCl in pH 2.0 buffer can partially remove tip protein from pilus rods without depolymerization.

Purification of tip protein

- 10 1. Mix concentrated tip protein with SDS-PAGE sample treatment buffer without the SDS and β -mercaptoethanol. The ratio is 2.5 ml of pilus prep to 0.3 ml of sample treatment buffer.
2. Load the sample to a 12% SDS-PAGE (0.1% SDS) in Prep-15 Cell (Bio-Rad) with the length of stacking gel of 0.8-1.0 cm and running gel of 5cm.
3. Run the gel at 300 volt with cooling system for 6-8 hours, and monitor the elution at 280 nm.
4. Pool the fractions containing tip protein and 20 concentrate.
5. Determine the purity of the pooled fractions by mini-SDS-PAGE. The identification of purified tip protein by anti-KLP1-MBP fusion protein is shown in Figure 4. The binding activity of purified tip protein with human 25 red cell ghosts is shown in Figures 5 and 6. Figure 7 compares adhesin proteins from different LKP type pili by SDS/PAGE.

Example 8: Serotype Analysis

The *Haemophilus influenzae* (*Hflu*) bacterioplex is a 30 differentiated complex of bacterial phases, or cell types, socially organized to facilitate the protein appendages expressed on the surface of *Hflu*, and also secreted from *Hflu* in free form, carrying specific adhesion determinants

- 38 -

for binding to human cell membrane receptors. Pili adapt pathogenic bacteria to live in vertebrate hosts by mimicking the functions of the host's own proteins. Pilus functions include attaching bacteria to a variety of host cells and tissues and stimulating the host's immune system in ways which benefit the bacteria and damage the host. Pili are transmission, virulence, dissemination, pathogenicity and immunity factors in most bacterial diseases.

The expression of pili is controlled by a genetic switching mechanism, phase variation, in which pilus expression and pilus type are switched on and off at probabilities which vary with and are determined by conditions and signals in the immediate environment of the bacteria. Under some conditions the switching probabilities can be very high, as high as 10^{-2} per bacterial cell division. Under other environmental conditions the probability of the same phase switch can be 10^{-6} or lower. Phase switching is accompanied by both reversible and irreversible rearrangements in the DNA of pilus operons. Phase switching during *in vitro* growth is frequently accompanied by deletions to pilus operon genes such that nonpiliated phases remain irreversibly in that phase.

By purifying *Hflu* pili from different isolates and producing antisera to the purified preparations distinct LKP pilus serotypes have so far been identified. The expression of the different serotypes is used as a marker to identify the different piliation phases of the *Hflu* bacterioplex.

- 39 -

TABLE 1

| | | L=1 | L=2 | L=3 | D=3 | D=4 |
|----|-----------------|------|-----|-----|-----|-----|
| | LKP1 | N=4 | 0 | 0 | 4 | 0 |
| | LKP2 | N=2 | 0 | 1 | 1 | 0 |
| | LKP3 | N=0 | 0 | 0 | 0 | 0 |
| 5 | LKP4 | N=1 | 0 | 1 | 0 | 0 |
| | LKP5 | N=5 | 0 | 1 | 4 | 0 |
| | LKP6 | N=12 | 0 | 2 | 8 | 1 |
| | LKP7 | N=3 | 0 | 0 | 2 | 0 |
| | LKP8 | N=0 | 0 | 0 | 0 | 0 |
| 10 | LKP9 | N=0 | 0 | 0 | 0 | 0 |
| | LKP10 | N=26 | 1 | 8 | 17 | 2 |
| | LKP11 | N=22 | 0 | 6 | 16 | 0 |
| | LKP12 | N=12 | 0 | 3 | 7 | 2 |
| | LKP13 | N=0 | 0 | 0 | 0 | 0 |
| 15 | LKP14 | N=9 | 1 | 2 | 6 | 1 |
| | LKP15 | N=6 | 0 | 5 | 1 | 0 |
| | LKP16 | N=9 | 0 | 4 | 5 | 3 |
| | LKP17 | N=17 | 0 | 6 | 11 | 2 |
| | LKP18 | N=12 | 1 | 4 | 7 | 1 |
| 20 | LKP19 | N=3 | 0 | 1 | 3 | 0 |
| | LKP20 | N=15 | 1 | 6 | 8 | 3 |
| | Total Strains = | 77 | 4 | 50 | 99 | 15 |
| | | | | | | 136 |

25 L=1 is length <0.2 μ L=2 is length <0.2 μ <0.5 μ L=3 is length <0.5 μ

D=3 is 3nm diameter ("thin")

D=4 is 4nm diameter ("thick")

30 The frequency of each LKP serotype was determined for all serotypable cultures and for all cultures expressing

-40-

by counting types on both single expressors and multiple expressors. Sixteen of the 20 serotypes were found on typically LKP pilated cultures and 90% of these cultures were serotypable in the 20-type system. The frequency
5 distribution of serotypes for these cultures is shown in Table 1.

Three different LKP pilus operon genes were selected, the pilin gene, anchor gene and adhesin gene, which had all exhibited sequence similarity among different
10 serotypes in multiple sequence alignments, but were also characteristic of *Hflu* LKP pili. Sequences were selected from these genes that would serve as suitable primer sequences flanking each gene for use in a PCR reaction.

LKP1 Pilin: HF2 5' >AGCTGGATCCTTGTAGGGTGGCGTAAGCC<3'
15 (SEQ ID NO:16)
HF1 5' > AACGGATTCGTTGCTGTTATTAAGCCTT<3'
(SEQ ID NO:17)

LKP1 Anchor: R5 5' >GCCGCACCTTGATGAACG>3'
20 (SEQ ID NO:18)
R3 5' >GGCAAATACGCACCGCTAAAT>3'
(SEQ ID NO:19)

LKP1 Adhesin: A5 5' >CGGACGAAGATGGTACAACGA>3'
(SEQ ID NO:20)
A31 5' >CCAAGCTTGGCCCCACATTATTATTGATATGACA>3'
25 (SEQ ID NO:21)

All three pairs of primers were synthesized and used in a PCR reaction to amplify segments of DNA extracted from *Hflu* isolates.

Data showing the presence of LKP pilus operons in
30 tested *Haemophilus influenzae* strains is shown in Table 2.

-41-

| TABLE 2 | | | | | | |
|---|-----------------|-------|----------|-------|-------|----------------|
| CORRELATION BETWEEN THE PRESENCE OF LKP PILUS OPERON GENETIC MATERIAL IN <i>H. INFLUENZAE</i> ISOLATES AND THE EXPRESSED LKP PARAMETERS OF PILIATION AND HEMAGGLUTINATION | | | | | | |
| | LKP Parameter | Total | PCR Done | PCR + | PCR - | Fraction PCR + |
| 5 | Pilus Length 0 | 74 | 68 | 59 | 9 | 59/68 |
| | Pilus length 3 | 101 | 93 | 82 | 11 | 82/93 |
| 10 | HA+ | 148 | 139 | 115 | 24 | 115/139 |
| | HA- | 166 | 149 | 119 | 30 | 119/149 |
| 15 | Pilus Diam. 3 | 40 | 38 | 28 | 10 | 28/38 |
| | Pilus diam. 4 | 172 | 159 | 136 | 23 | 136/159 |
| 20 | Serotypable | 189 | 173 | 149 | 24 | 149/173 |
| | Not serotypable | 54 | 63 | 53 | 10 | 53/63 |
| 25 | | | | | | |
| 30 | | | | | | |

1. Pilus length 0 means nonpiliated.
 2. length 3 means >0.5 microns (longest, typical of LKP pili).
 3. HA+ means positive for hemagglutination of human red blood cells; typical of LKP pili. (These isolates are not recalcitrant by definition.)
 4. HA- means negative for hemagglutination of human red blood cells; typical of SNN pili. (These isolates are recalcitrant since all isolates were hemadsorbed at least once.)
 5. Pilus diameter 3 means the isolates express pili with diameters typical of SNN pili.
 6. Pilus diameter 4 means the isolates express pili with diameters typical of LKP pili.
 7. Serotypable means the isolates agglutinate under standard conditions with at least one of the LKP pilus typing antisera in the 1-20 system.
 8. Not serotypable means the isolates do not agglutinate with any of the LKP pilus typing antisera in the 1-20 system.

Example 9: Hybridization Assay for *Haemophilus Influenzae* Assay Probe Construction

An approximately 1100 bp fragment from plasmid pHF1 (Karasic, R. et al., *Pediatr. Infect. Dis. J.* 8 (Suppl.):S62-65 (1988)) which contains the LKP1 serotype operon was amplified by PCR using primers which hybridize at the 5' and 3' ends of the *hipA* gene. This gene encodes the tip adhesin protein of the LKP1 pili. The PCR reaction included digoxigenin labeled dUTP along with the

-42-

four dNTPs to label the PCR reaction product with digoxigenin. This probe was electrophoresed on an agarose gel and purified by cutting out the ~1.2 kb band and extracting the DNA by standard methods. The probe was
5 redissolved in 30 μ l of appropriate buffer.

Hybridization Assay

Eleven randomly chosen *Haemophilus influenzae* clinical isolates were grown on BHI-XV plates at 37°C with 5% CO₂, and also streaked onto BHI agar. All isolates grew
10 only on the BHI-XV plate, indicating that they were *H. influenzae*. The isolates included 2 *Hib* strains and 9 *NTHi*. The strains were inoculated onto a nylon membrane placed onto BHI-XV agar. Five clinical isolates of another respiratory pathogen, *Moraxella catarrhalis* were
15 also spotted onto the filter. The bacteria were grown overnight at 37°C in 5% CO₂. After growth, 2 *Bordetella pertussis* strains were spotted onto the filter. Filters were processed for colony hybridization according to the method of Maniatis et al. (*Molecular Cloning: A*
20 *Laboratory Manual*, 1991, Cold Spring Harbor Laboratories, Cold Spring Harbor, NY). Filters were blocked in pre-hybridization solution as described by Boehringer-Mannheim for the Genius™ system at 65°C for 3 hours. Colony debris was removed by gentle rubbing with wet paper towels. The
25 probe, 30 μ l, was added to 5 ml of pre-hybridization solution and boiled for 10 minutes to denature the DNA. Probe was immediately added to the filter and allowed to hybridize overnight at 65°C. Filters were washed in 2X SSC, 0.1% SDS, 2X for 5 min/wash at room temperature
30 followed by 2, 15 minute washes with 0.2X SSC, 0.1% SDS at 65°C. Bound probe was detected using alkaline phosphatase labeled anti-digoxigenin antibodies as described by the manufacturer. Results are shown in Table 3.

- 43 -

Table 3 HYBRIDIZATION OF dig-LABELED LKP 1 TIP PROBE TO RANDOM CLINICAL ISOLATES

| Bacterial Strain | Number of Positive Results | | | # Total |
|-----------------------|----------------------------|-------------|-----------|---------|
| | Strong Signal | Weak Signal | No Signal | |
| <i>H. influenzae</i> | 4 | 4 | 3 | 11 |
| <i>M. catarrhalis</i> | 0 | 0 | 5 | 5 |
| <i>B. pertussis</i> | 0 | 0 | 0 | 2 |

The probe was specific for *H. influenzae* with no hybridization seen with either *M. catarrhalis* or *B. pertussis*.

Hybridization Assay of Nontypable Strains of Haemophilus

5 influenza pili

Ten LKP pili expressing NTHi strains which express differing serotypes of LKP pili, along with Hib Eagan were grown on a nylon filter overlayed onto chocolate agar at 37°C in 5% CO₂. An additional NTHi isolate was also 10 included. After growth, two strains appeared yellow on the filter which was suggestive of non-Haemophilus bacteria, so they were tested by growth on BHI and BHI-XV. This experiment showed them to be contaminants and not NTHi. The filter was removed from the agar and processed 15 as described above. The probe from the first experiment was reboiled and added to the filter as before, except that the hybridization temperature was lowered to 62°C. The filter was washed as before except that the wash temperature was also 62°C. Bound probe was detected as 20 above. Results are shown in Table 4.

- 44 -

Table 4. HYBRIDIZATION OF dig-LABELED TKP TIP PROBE TO LKP TYPE STRAINS

| LKP Serotype | Signal with probe | No signal with probe | ID of strain |
|--------------|-------------------|----------------------|--------------|
| 5 | Strong | | NTHi |
| 2 | Moderate | | NTHi |
| 9 | Strong | | NTHi |
| 1 | Strong | | NTHi |
| 6 | Moderate | | NTHi |
| 13 | Strong | | NTHi |
| 4 | Strong | | NTHi |
| 7 | Moderate | | NTHi |
| | | X | Contaminant |
| | | X | Contaminant |
| 10 | Weak | | NTHi |
| 4 | Strong | | Hib |

The results set forth above establish that the DNA probes hybridized selectively to *Haemophilus influenzae*.

Equivalents

Those skilled in the art will recognize, or be able to ascertain using not more than routine experimentation, many equivalents to the specific embodiments of the invention described herein. Such equivalents are intended to be encompassed by the following claims.

- 45 -

TABLE 5

AAGCTTGCATGCCCGCAGGTCGACTCTAGAGGATCATTCCATTGTGTTTATCTTTAATAAACACCAAGGT
 GAGGTAGAAATATTCAAGTCAGGATTTGCGTAAACGATCGGCTAATAATCAAATACATGT
 TGATTAACGAAGTTTATGATTGCTGAGTAATTCAAGTCAGTCAAAGGCCTTTCCAGCGTCAATTCCGCC
 GTGATGATCGCATTTCAGGTAAGTCAGGCTAAGGGTCAACATAAAATCTAAA
 GGTGCACCAGCGTAACCTAACATTCTGCCAGTTGCCGAGAACATAACGGTTGGGTATAAGGTG
 GAGTTTGCTATAATTCTGTTAAATTACGAAAAACACCGCATTAAAGTGCAGTCAGATCTGAA
 GATATTTTATGTGCGTGGATCGGATTGTCCAGTACAGCACGAGTTGGCTTCACGGAAAGATTGCAAGC
 GTGAAAGCAATTCTGCATCCCACCTGCTAGAATTGGGCTGCTAACAAACCCAGCATTGCCGCGCTGCAG
 AGCCAATCGCTAATGTTCCGACTGGAATCCCTTTGGCATTGCACAATTGAATAAGGCTATCCACACCAC
 TTAACATAGAACCTTTACTGGCACCCCCAGCACTGGCACAAGTGTGCTGCATACCCAGGTAAT
 GTGCCGACCGCCTGCACCAGCAATAATTACTTATAGCCATTTCGTGCTTCGGCAAATTGAAAA
 GTTTATCAGCGTACGATGGCAGAGACACTTCCACATGATAAGGCACGTTAATTCACTAAAATCTGAG
 TTGCTCTTGCATAGTAGCCAATCATTGGCACCCATCACAACGGCAATTGTGCTAGTTTGACATGC
 TATTCTCAATTCTAATTAAAACGTGGTAGAATAGCATAGATTACATATCGAGCAAACGTTGC
 TATTATGTACGTATTAATGGGATTATTTATAATTATTGTATTAAATTAGTAACACTACTTGATA
 CCAAATTAAATGGCGATAGTTATATGGACGAACGTTAATTAGATAAGCTCGACAATCAAATCT
 ACATTAAATTGGAATGAATTAGTTCTTGTAGCTAACAGGTTATGAAAAGCGAGAAATGGCAGGTTCT
 CGAGTGAGATTTATAATAGAACACTCGAACATATGATTGTACACAAGCCTCATCTGAAAATTATATT
 AAAGCGGTGTTAAAGTCAGTGAAAGAATCATTAAAACAGGTAGGTATTCTATGAAGTTATTAAATTATA
 AAGGTTATGTTGGCACGATTGAGGCGATTAGAAAACAAATATATTATTGGCAAACCTGCTTACATTGTG
 ATTAGTACCTACGAAGCAGAGTCATTATCTGAGTTAGAAAAAGAATTCAATCTGTTGATTATATT
 TACAAGATTGTTGAAATTAGGTAAAGAACCGAATAAGCCTTTAAAGGTGTATTATGACGAAATGGCG
 AGGAATTGCATAGAGAACGATCATAGCTGGCGATCGTCTCTTAATGCTTGTGACGGAAGCAATT
 AAGAAAAAAATTCTCGTAAAAACCAAGTTAAGATAACAAACGTATTACATTTCATCACGTTAG
 CTGGCGTAAGCCATGTAGAGACACATAAAAAGATTGTAGGCTAGGCGTAAGCTCACGTGGATAACATAT
 AAAAGATTGTAGGGTGGCGTAAGCCCACGCGAGGATATAACAAACACGTGGCTTAGATTGCATTACAT
 TAGGAATTATCGTAAGCAATTGGAAATCAACTGAGGATTCTACTTACAGCTCCGCTTGAGCTGTTGC
 • GluTyrAlaIleGlnPheAspValSerSerGluValLysGlyAlaGluAlaGlnAlaThrAla
 ATAGTATCTAGCGATATAGTGTAAATTCACTTGTGTTACCGTTAATTGTAGCTTTCTGAAATATGATT
 • TyrTyrArgAlaIleTyrHisLeuLysValAsnAsnGluGlyAsnIleThrAlaLysGlySerIleHisAsn
 TTTATTCACTAGTTGTTGTTGCAACGTCATTGTATTGCTATGCGTAAATCTGTTGTTCCGTTGCCGAC
 • LysAsnValThrGlnGlnThrAlaValAspAsnThrAsnSerHisThrPheAspThrThrGlyAsnGlyVal
 AACTTCAATTGCATCTGTACCATAGCATAAAAGCTGGATATTACATTCTGCACTTCCGTTAGATTGCATTACAT
 • ValGluIleAlaAspThrGlyAsnAlaAspPheLeuGlnIleAsnValAsnGlnAlaAlaAspAsnGlySer
 TTTTGTATTCTTAATGTATATTCACTTGTGATTCTGCACTTCCGTTAGAAATAGAAATAAGCTCCAACCTT
 • LysThrAsnLysLeuThrTyrGluAsnAsnGluAspAlaAsnLysTrpSerTyrPheTyrAlaGlyValLys
 TGTTGCAACAGGTTATTATTAGTAGTAGTAGTAGTGAACAAATTCTAAATTGTAAATGGTGGTTGG
 • ThrAlaValProLysAsnAsnThrThrThrSerCysAsnGluLeuAsnIleThrPheProThrPro

- 46 -

TABLE 5 (cont.)

CATCGCTGTATCTTTTTAGTTTTAAATGATTTACCCACATCATTAAACTACGCTCATATTTTACT
 ▶ MetAlaThrAspLysLysThrLysLeuHisAsnLysGlyValAspAsnLeuValValSerMetAsnLysSer
 ATCCGTTTCACCTACAAGTATTCTAACAAACCTACCAAGAAAGTAACCTTACCAAGATGTTAGTACT
 ▶ AspThrLysValLysCysThrAsnGluValValLysGlyPhePheThrValLysGlySerThrGluThrSer
 TACTTGAGGATCAGCAGCATTGGTGCACATGCCATAAAATTAAAGCTACCAAGAAGTGTGTTCTATAAT
 ▶ ValGlnProAspAlaAlaAsnThrAlaPheAlaLeuIleLeuSerGlyLeuLeuThrLysLysMetIle
 AAATTGCTCCATAAAAGAGGTTGTGCCTATAAAATAAGCAATAAGATTAAATAAAACGTTATTAAAAT
 ▶ PheGlnGluMet
 GCCAAAGGCTTAATAAACAGCAAACCTTGTTCACAAAAAGTAACACTTCCATTATATATATA
 TATATATAATTAAAGCCCTTTGAAAAATTTCATATTTTGAAATTAACTCGCTGTAGGTTGGGTTTG
 CCCACATGGAGACATATAAAAGATTGTAGGGTGGCGTAAGCCCACGCCAACATCATCAAACAACTGT
 AATGTTGTATTAGGCACGGTGGCCTATGCCCTGCCTACGGGAAATGAATAAGGATAAAATATGGGCTTAGC
 ▶ MetAsnLysAspLysTyrGlyLeuSer
 CCAGTTATGGATTAAATTATGTTGAAATGGGAAACAAATGTTAAAAAACACTTTATTTTACCGCA
 ▶ ProValTyrGlyPheAsnTyrValGluMetGlyLysThrMetPheLysLysThrLeuLeuPhePheThrAla
 CTATTTTGCCGCACCTTGTCGATTTCAAGCCAATGCAGATGTGATTATCACTGGCACCGAGTGATTAT
 ▶ LeuPhePheAlaAlaLeuCysAlaPheSerAlaAsnAlaAspValIleIleThrGlyThrArgValIleTyr
 CCCGCTGGGCAAAAGATTGTATCGTGAAGTTAGAAAACAATGATGATTGGCAGCATTGGTGCAGCCTGG
 ▶ ProAlaGlyGlnLysAsnValIleValLysLeuGluAsnAsnAspAspSerAlaAlaLeuValGlnAlaTrp
 ATTGATAATGGCAATCCAAATGCCATCCAAATACACCACAAACCCCTTTGTGATTACCCGCCTGTTGCT
 ▶ IleAspAsnGlyAsnProAsnAlaAspProLysTyrThrLysThrProPheValIleThrProProValAla
 CGAGTGGAAAGCGAAATCAGGGCAAAGTTGCGGATTACGTTCACAGGCAGCGAGCCTTACCTGATGATCGC
 ▶ ArgValGluAlaLysSerGlyGlnSerLeuArgIleThrPheThrGlySerGluProLeuProAspAspArg
 GAAAGCCTCTTTATTAAATTGTTAGATACTCCGCCAAACCTGATGCGGATTCTGGCAAAACACGGC
 ▶ GluSerLeuPheTyrPheAsnLeuLeuAspIleProProLysProAspAlaAlaPheLeuAlaLysHisGly
 AGCTTATGCCATTGCTCACGTTGAAGTTGTTATGCCCTGCGAAACTCTCGATGGATTCT
 ▶ SerPheMetGlnIleAlaIleArgSerArgLeuLysLeuPheTyrArgProAlaLysLeuSerMetAspSer
 CGTGATGCAATGAAAAAGTAGTGTAAAGCCACACCTGAAGGGTGTGGTGGATAATCAAACCCCTTAT
 ▶ ArgAspAlaMetLysValValPheLysAlaThrProGluGlyValLeuValAspAsnGlnThrProTyr
 TATATGAACATACATTGTTGTTACATCAAATAACCTGCGAAAATGTCAAATGGTTGCCCTTTTCT
 ▶ TyrMetAsnTyrIleGlyLeuLeuHisGlnAsnLysProAlaLysAsnValLysMetValAlaProPheSer
 CAAGCGGTATTGAAGCCAAAGGCGTGCCTCTGGCGATAAAATTGAAATGGGTATTGGTTATGATTACGGT
 ▶ GlnAlaValPheGluAlaLysGlyValArgSerGlyAspLysLeuLysTrpValLeuValAspTyrGly
 GCCGACCAAGAAGGCGAAGCCATCGCTCAATAATAGCGAACTAGTGTAGGGTGGCCTTAGACCACCGATTA
 ▶ AlaAspGlnGluGlyGluAlaIleAlaGln
 ACCATAACAAAGGTGGCTGAAGCCCACCTACAACCAAAAGAACGATTAATCTGTGAAAACAAAAATT
 TCCCTTAAATAAAATTGCGTTGCTTCACTGCTATTGGCAAATCCTTACCGTGGCGGGAGATCAATT
 TGATGCCTCTCTTGGGAGATGGTTCGGTGTGGCGTTGATTGCCCCATTAAATGAAAAATGCCGT
 GTTACCAAGGGCGTTATGAAGCTCAAATCTATGTGAAATTGAAAGAAAAAGGCGTAAGCGATATTATTTG

- 47 -

TABLE (cont.)

TGATAATCCTGCCACAGGTGGACAGAATTATGCTTTACGCCTAAACTCAAGAAATGCTGGATTTGATGGA
 ▶ MetLeuAspLeuMetAs
 TGAAGCCATTGTGAAATGCCCAATTCAAAGATGACACTTGTGCTTGCTTCTGATGCTATTCTAAAGG
 ▶ pGluAlaIleValLysSerProAsnSerGluAspAspThrCysValPheAlaSerAspAlaIleProLysG1
 CACGTTGAATATCAAAGCGGCAGAAATTGAAACTTGAGCTCCCTCAAGCTCTCACTATTGCCGACC
 ▶ yThrPheGluTyrGlnSerGlyGluMetLysLeuLysLeuGluLeuProGlnAlaLeuThrIleArgArgPr
 AAGAGGCTATATTGCGCCATCTCGCTGGCAAACGGCACCAATGCCGTTTGCAAAATTACGATATCAACTA
 ▶ oArgGlyTyrIleAlaProSerArgTrpGlnThrGlyThrAsnAlaAlaPheAlaAsnTyrAspIleAsnTy
 TTATCGTTCTGGTAATCCGAAGTAAAATCCGAAAGTTGTATGTGGGCTTGCGTAGTGGCGTAAATTG
 ▶ rTyrArgSerGlyAsnProGluValLysSerGluSerLeuTyrValGlyLeuArgSerGlyValAsnPheG1
 CAACTGGGCATTGCGTCATAGCGGCAGTTAGCCGTTTGAAAACCAAAGTAGCTCGGGTTTACTGATAA
 ▶ yAsnTrpAlaLeuArgHisSerGlySerPheSerArgPheGluAsnGlnSerSerSerGlyPheThrAspLy
 GGGCAAAATCATTACGAACGTGGCGATACCTATTACAACGAGATTGCGCCCTGCTTGTGGCAATGTCAC
 ▶ sGlyLysAsnHisTyrGluArgGlyAspThrTyrLeuGlnArgAspPheAlaLeuLeuArgGlyAsnValTh
 TGTTGGGATTTCAGCACTGCCGCATTGGCAGAAATTGGTATGCGTGGTTGCGTATTGCGCTCTGA
 ▶ rValGlyAspPhePheSerThrAlaArgIleGlyGluAsnPheGlyMetArgGlyLeuArgIleAlaSerAs
 TGATAGAATGCTTCCCCATCACAAACGTGGTTTGCCCCAGTGGTGGCTGGCAAAACACAAAGCCAA
 ▶ pAspArgMetLeuAlaProSerGlnArgGlyPheAlaProValValArgGlyValAlaAsnThrAsnAlaLy
 AGTCAGCATCAAACAAAATGGCTATACGATTATCAAATCACCGTCCCGCAGGGCCTTCGTGATTAACGA
 ▶ sValSerIleLysGlnAsnGlyTyrThrIleTyrGlnIleThrValProAlaGlyProPheValIleAsnAs
 TTTGTATGCCAGCGTTAGCGGCGATTTAACGGTGGAAATCCAAGAAAGTGTGGTAAAGTGCAGTCATT
 ▶ pLeuTyrAlaSerGlyTyrSerGlyAspLeuThrValGluIleGlnGluSerAspGlyLysValArgSerPh
 TATTGTGCCGTTCTAATCTTCCCCGTTAACGCGTGTGGGGATTGCGTTATCAATTAGCTGGCGGACG
 ▶ eIleValProPheSerAsnLeuAlaProLeuMetArgValGlyHisLeuArgTyrGlnLeuAlaGlyGlyAr
 TTATCGAATTGACAGCCGCACCTTGATGAAACGTGTGTTACAAGGCGTGTGCAATATGGTTAACTAATCA
 ▶ gTyrArgIleAspSerArgThrPheAspGluArgValLeuGlnGlyValLeuGlnTyrGlyLeuThrAsnHi
 TCTCACGCTGAATTCAAGCCTGCTTATACACGTCAATTACGTGCAGGGCTGGTTGGTTAAATAC
 ▶ sLeuThrLeuAsnSerSerLeuLeuTyrThrArgHisTyrArgAlaGlyLeuPheGlyPheGlyLeuAsnTh

 GCCGATTGGGGCGTTCTGCTGATGCCACTTGGTCGCACGCTGAATTCCGCTAAACATGTGAGCAAAA
 ▶ rProIleGlyAlaPheSerAlaAspAlaThrTrpSerHisAlaGluPheProLeuLysHisValSerLysAs
 CGGCTACAGCTTGCACGGCAGTTAGTATTAACTCAATGAAAGTGGCACCAATATCACGTTGGCAGCCTA
 ▶ nGlyTyrSerLeuHisGlySerTyrSerIleAsnPheAsnGluSerGlyThrAsnIleThrLeuAlaAlaTy
 TCGCTATTCTCACGGGATTACACCTTAAGCGACACCATTGGCTTAACCGCACTTCAGACAATTAG
 ▶ rArgTyrSerSerArgAspPheTyrThrLeuSerAspThrIleGlyLeuAsnArgThrPheArgGlnPheSe
 CGGTGCGTATTGCGCTGAAATTACCGCCAAAAAATCAGTTCAAGTGAGTTAAGCCTAAAGTCTGGGGAA
 ▶ rGlyAlaTyrLeuProGluIleTyrArgProLysAsnGlnPheGlnValSerLeuSerGlnSerLeuGlyAs
 TTGGGGAAATCTCTATCTTCAGGACAAACCTATAATTATTGGGAAAACGTGGCACGAATACGCAATATCA
 ▶ nTrpGlyAsnLeuTyrLeuSerGlyGlnThrTyrAsnTyrTrpGluLysArgGlyThrAsnThrGlnTyrGl

-47/1-

TABLE 5 (cont.)

AGTTGCCTATTCAAACAGCTTCCACATTCTTAATTACTCTGTAAACCTCTCACAGAGTATTGATAAAAGAAAC
 ▶ nValAlaTyrSerAsnSerPheHisIleLeuAsnTyrSerValAsnLeuSerGlnSerIleAspLysGluTh
 GGGCAAAACGTGACAACAGCATTATTAAGTCTCAGCCTGCCATTAGGCATAACCATTCTGCAGATAGTAG
 ▶ rGlyLysArgAspAsnSerIleTyrLeuSerLeuSerLeuProLeuGlyAspAsnHisSerAlaAspSerSe
 TTATTCTCGCAGTGGTAACGATATTAACCAACGACTTGGCTAAATGGCTTTGGTGAACGTCAATCG
 ▶ rTyrSerArgSerGlyAsnAspIleAsnGlnArgLeuGlyValAsnGlySerPheGlyGluArgHisGlnTr
 GAGTTATGGTATTAACGCTTCACGCAATAATCAAGGCTATCGCAGTTATGACGGTAATCTTTCGCATAACAA
 ▶ pSerTyrGlyIleAsnAlaSerArgAsnAsnGlnGlyTyrArgSerTyrAspGlyAsnLeuSerHisAsnAs
 TAGCATTGGTAGTTACCGTGCTTCTTATTACGTGATAGCCTCAAAAATCGCTCCATCTCACTGGCGCAAG
 ▶ nSerIleGlySerTyrArgAlaSerTyrSerArgAspSerLeuLysAsnArgSerIleSerLeuGlyAlaSe
 CGGTGCTGTCGTCGGCGCACAAACACGGTATTACCTAACGCAACCTGTTGGCAAAGTTTGCCATTATTCA
 ▶ rGlyAlaValValAlaHisLysHisGlyIleThrLeuSerGlnProValGlyGluSerPheAlaIleIleHi
 CGCCAAAGATGCCGCAGGAGCAAAAGTGGAAATCAGGTGCAATGTGAGCCTTGATTATTCGGCAATGCGGT
 ▶ sAlaLysAspAlaAlaGlyAlaLysValGluSerGlyAlaAsnValSerLeuAspTyrPheGlyAsnAlaVa
 TATGCCTTACACCAGCCCCTATGAAATCAATTATATCGGTATCAATCCATCTGATGGGAGGCGAATGTGGA
 ▶ lMetProTyrThrSerProTyrGluIleAsnTyrIleGlyIleAsnProSerAspAlaGluAlaAsnValG1
 ATTTGAAGCCACTGAACGCCAAATCATTCCCTCGTGCCTTCAATTAGCTTAGTGTAGATTCCGCACGGGCAA
 ▶ uPheGluAlaThrGluArgGlnIleIleProArgAlaAsnSerIleSerLeuValAspPheArgThrGlyLy
 AAATACAATGGTGTATTAAACCTCACTTGCCTAACGCAATGGCGAGGCCAGTGCCAATGGCATCCACCGCACAAAGA
 ▶ sAsnThrMetValLeuPheAsnLeuThrLeuProAsnGlyGluProValProMetAlaSerThrAlaGlnAs
 TAGCGAAGGGGCATTGTGGCGATGTGGTGCAGGGTGGTGTGCTTTCGCTAATAAACTTACCCAGCCAAA
 ▶ pSerGluGlyAlaPheValGlyAspValValGlnGlyGlyValLeuPheAlaAsnLysLeuThrGlnProLy
 AGGCGAGTTAACGTCAAATGGGGTGAGCGAGAAAGCGAACATGCCCTTCCAATATCAAGTTGATTGGA
 ▶ sGlyGluLeuIleValLysTrpGlyGluArgGluSerGluGlnCysArgPheGlnTyrGlnValAspLeuAs
 TAACGCACAAATACAAAGTCACGATATTCAATGCAAACCGCAAATAATAATTGAAGAGGATTATGCAA
 ▶ pAsnAlaGlnIleGlnSerHisAspIleGlnCysLysThrAlaLys ▶ MetGln
 AAAACACCCAAAAAAATAACCGCGCTTTCCATCAAAATCCACTGCTACTTGTAGGGAGCAAATTATAGT
 ▶ LysThrProLysLysLeuThrAlaLeuPheHisGlnLysSerThrAlaThrCysSerGlyAlaAsnTyrSer
 GGAGCAAATTATAGTGGCTCAAATGCTTAGGTTCATCGTCTGGCTTGCTTGCGTGGCTCTGCTT
 ▶ GlyAlaAsnTyrSerGlySerLysCysPheArgPheHisArgLeuAlaLeuLeuAlaCysValAlaLeuLeu
 GATTGCATTGTGGCACTGCCTGCTTATGCTTACGATGGCAGAGTGACCTTCAAGGGGAGATTAAAGTGAT
 ▶ AspCysIleValAlaLeuProAlaTyrAlaTyrAspGlyArgValThrPheGlnGlyGluIleLeuSerAsp
 GGCACATTGTAACGAAACAGACAGCAGCCAAATCGCACGGTTACCCGCCAACAGTGGAAAAGCTAATTIA
 ▶ GlyThrCysLysIleGluThrAspSerGlnAsnArgThrValThrLeuProThrValGlyLysAlaAsnLeu
 AGCCACGCAGGGCAAACCGCCGCCCTGTGCCTTTCCATCACGTTAAAGAATGCAATGCAGATGATGCT
 ▶ SerHisAlaGlyGlnThrAlaAlaProValProPheSerIleThrLeuLysGluCysAsnAlaAspAspAla
 ATGAAAGCTAATCTGCTATTAAAGGGGAGACAACACAAAGGGCAATCTTATCTTCCAATAAGGCAGGC
 ▶ MetLysAlaAsnLeuLeuPheLysGlyGlyAspAsnThrThrGlyGlnSerTyrLeuSerAsnLysAlaGly

-47/2-

TABLE 5 (cont.)

AACGGCAAAGCCACCAACGTGGGCATTCAAATTGTCAAAGCCGATGGCATAGGCACGCCTATCAAGGTGGAC
 ▶ AsnGlyLysAlaThrAsnValGlyIleGlnIleValLysAlaAspGlyIleGlyThrProIleLysValAsp
 GGCACCGAAGCCAACAGCGAAAAAGCCCCCGACACAGGTAAAGCGAAAACGGCACAGTTATTCAACCCCGT
 ▶ GlyThrGluAlaAsnSerGluLysAlaProAspThrGlyLysAlaGlnAsnGlyThrValIleGlnProArg
 TTTGGCTACTTTGGCTCGTTATTACGCCACAGGTGAAGCCACCGCAGGCACGTTGAAGCCACTGCAACTTT
 ▶ PheGlyTyrPheGlySerLeuLeuArgHisArg
 TGAAAGTGCAGTATAACTAAAAATTTATTATCCAGTGAAAAAAATGAATAAGAAATCGTATATAAAATCATTAC
 ▶ MetAsnLysLysSerTyrIleAsnHisTyr

TTAACCTTATTTAAAGTTACTACTTTACTATTTACTCTTCAGTAATCCTGTATGGCAAATATAAAAACA
 ▶ LeuThrLeuPheLysValThrThrLeuLeuPheThrLeuSerSerAsnProValTrpAlaAsnIleLysThr
 GTTCAGGGAACAACTAGTGGTTTCCACTCTAACAGAACCTTCACATTAAATGGCAATTGCAATGGAAT
 ▶ ValGlnGlyThrThrSerGlyPheProLeuLeuThrArgThrPheThrPheAsnGlyAsnLeuGlnTrpAsn
 GTGAGTGCCTCTAACACCAGCTTATATTGTTCTCTCAAGCAAGAGATAATCTGATACAGTACATATTCAA
 ▶ ValSerAlaLeuGlnProAlaTyrIleValSerSerGlnAlaArgAspAsnLeuAspThrValHisIleGln
 TCTTCTGAAATTAAATGCTCCAACAAATTCTTACCTAGCTCCATTAAATAATTGGATAATACGAAATCAGCAGTA
 ▶ SerSerGluIleAsnAlaProThrAsnSerLeuAlaProPheAsnAsnTrpIleAsnThrLysSerAlaVal
 GAGCTAGGTTATAGCTTGGGGCATTACTTGACTAGTAATCCTGCCAACAAATGAAATTACCAATTATTAA
 ▶ GluLeuGlyTyrSerPheAlaGlyIleThrCysThrSerAsnProCysProThrMetLysLeuProLeuLeu
 TTTCATCCTGATCTTACTAATTAACTCCACCTGGAAAGAAAAATTCTGATGGAGGGAGATTAAATTAA
 ▶ PheHisProAspLeuThrAsnLeuThrProProGlyLysAsnSerAspGlyGluIlePheLysLeu
 CATAATGAATCTAATTAGCGTCTCTTCAAATTGGAGTAAACAGAATACTCTCTAGATTGGTTAA
 ▶ HisAsnGluSerAsnLeuGlyValSerPheGlnIleGlyValLysThrAsnThrSerLeuAspTrpValAsn
 GCTAAGAATAATTAGCTCTCTAAAGTTTAATGGTGCCTTTAATTCTAGCGATAAAATATCTTGCAT
 ▶ AlaLysAsnAsnPheSerSerLeuLysValLeuMetValProPheAsnSerSerAspIleSerLeuHis
 TTACGTGCTAAATTTCATTAAACAGATTTCATCGCTAAATAATGATATTACTATTGACCTATGAAT
 ▶ LeuArgAlaLysPheHisIleLeuLeuThrAspPheSerSerLeuAsnAsnAspIleThrIleAspProMetAsn
 ACTAGTATAGGCAAAATTAAATCTTGAACAGTGGCTCAACAGGAATTCTGTTAAATATGTAGGT
 ▶ ThrSerIleGlyLysIleAsnLeuGluThrTrpArgGlySerThrGlyAsnPheSerValLysTyrValGly
 GAGGATAAGGGAGATATATCTATTCTTAAACACCTAAAATTCTAAAAACAAACACGCCGATGT
 ▶ GluAspLysGlyAspIleSerIlePhePheAsnThrProLysIleIleLeuLysLysGlnGlnArgArgCys
 ACTCTGAATAATGCTCCAGTGAGGCCAAATCCAGTTAAATTACGAGCGGTAAAAAAACGTGAATTGGAGGCA
 ▶ ThrLeuAsnAsnAlaProValSerProAsnProValLysLeuArgAlaValLysLysArgGluLeuGluAla
 CAAAGTGAATGGAAAGGTGGACATTTCAGTTAAGAGTAATTGTGACAATACCACTTATAATAAGCCAAC
 ▶ GlnSerGluMetGluGlyGlyThrPheGlnLeuArgValAsnCysAspAsnThrThrTyrAsnLysAlaAsn
 GGCAAATGGTTATTCTGTAGTGAAAGTTACTTTACGGACGAAGATGGTACAACGAATAATGGAACAAAT
 ▶ GlyLysTrpLeuPheProValValLysValThrPheThrAspGluAspGlyThrThrAsnAsnGlyThrAsn

- 47 / 3 -

TABLE 5 (cont.)

- GACTTACTTCGACCCAAACAGGCAGCGGACAAGCCACAGGCAGCTTAAGAACGAGAAAATGGT
- ▶ AspLeuLeuArgThrGlnThrGlySerGlyGlnAlaThrGlyValSerLeuArgIleLysArgGluAsnGly ACAGAAACCGTAAACATCGGTGCTGATTCTGCTCAAATGGGAATGCTGGACAATTGAAATTACGAAACAA
 - ▶ ThrGluThrValLysTyrGlyAlaAspSerAlaGlnMetGlyAsnAlaGlyGlnPheGluLeuArgLysGln CCATCCCCTGCTGGTGGAGATCAATATGCTGAAGAAACTTCAAAGTCTATTACGTAAAAGACTCAACAAGA
 - ▶ ProSerProAlaGlyGlyAspGlnTyrAlaGluGluThrPheLysValTyrTyrValLysAspSerThrArg GGCACCTTAATCGAAGGAAAAGTCAAAGCCGCCACTTCACAATGTCATATCAATAATAATGTCGGGTG
 - ▶ GlyThrLeuIleGluGlyLysValLysAlaAlaAlaThrPheThrMetSerTyrGln GGAATATAAAGGCTGAAGGTTAAACTTCAGTCTTTATAGGAAAATACCATTGCAACTTAAGGATAAA
 - ▶ AATTTTATCCTAACAGCACAAATTAAAGGCTAACAGGTTAAACTTCAGTCTTTATAGGAAAATACCATTGCAACTTAAGGATAAA
 - ▶ MetLeuAlaLysAlaLysTyrArgLysAsp TACAAACAACCAGATTTACGGTCACAGACATTATTTAGATTTCACACTTGATCCTAAAAACTGTGGTG
 - ▶ TyrLysGlnProAspPheThrValThrAspIleTyrLeuAspPheGlnLeuAspProLysAsnThrValVal

ACTGCAACCACAAAATTCCAACGCTTAATAATGAAGCGACGTCTTACGTTAGACGGGCATAGCTTCCAG

 - ▶ ThrAlaThrThrLysPheGlnArgLeuAsnAsnGluAlaThrSerLeuArgLeuAspGlyHisSerPheGln TTTTCTTCTATTAAATTAAATGGCGAGCCATTCTGATTATCAACAAGATGGCGAGAGTTAACGCTCGAT
 - ▶ PheSerSerIleLysPheAsnGlyGluProPheSerAspTyrGlnGlnAspGlyGluSerLeuThrLeuAsp TTAAAAGACAAAAGTGCAGATGAATTGAGCTTGACGTTCTTGCCAGCCAAAATACGTCA
 - ▶ LeuLysAspLysSerAlaAspGluPheGluLeuGluIleValThrPheLeuValProAlaGluAsnThrSer TTACAAGGGCTATATCAGTCTGGCGAAGGTATTGTACGCAATGTGAGGGCGGAAGGTTCCGTCAAATCACT
 - ▶ LeuGlnGlyLeuTyrGlnSerGlyGluGlyIleCysThrGlnCysGluAlaGluGlyPheArgGlnIleThr TATATGCTTGATCGCCTGATGTGCTGGCGCCTTATATAATCAAATACGGCAGATAAAACCAAATATCCA
 - ▶ TyrMetLeuAspArgProAspValLeuAlaArgTyrIleIleLysIleThrAlaAspLysThrLysTyrPro TTCTTACTGTCGAATGGTAATCCGATTGCAAGTGGCGAATTAGAAGATGGTCGCCATTGGGTGGAATGGAAT
 - ▶ PheLeuLeuSerAsnGlyAsnArgIleAlaSerGlyGluLeuGluAspGlyArgHisTrpValGluTrpAsn GATCCCTTCCCACCAAGCTATTATGGCTTAGTGGCGGGAGATTNGGTTATTACAAGATAANTTT
 - ▶ AspProPheProLysProSerTyrLeuPheAlaLeuValAlaGlyAspXaaGlyLeuLeuGlnAspXaaPhe ATTACTAAAAGTGGTCGTGAAGTGGCTTAGAGCTTATGTGGATCGCGGTAACTTAAACCGTGCAACTGGG
 - ▶ IleThrLysSerGlyArgGluValAlaLeuGluLeuTyrValAspArgGlyAsnLeuAsnArgAlaThrGly GCAATGGAAAGTCTGAAAAAGCGATGAAATGGGATGAAGATCGCTTATTAGAATTACCTAGATATT
 - ▶ AlaMetGluSerLeuLysLysAlaMetLysTrpAspGluAspArgPheIleLeuGluPheTyrLeuAspIle TATATGATCGCGGCCGATTCCCTCCAATATGGGCCAATGGAAAATAAGGATTAAATATCTTAACTCT
 - ▶ TyrMetIleAlaAlaAspSerSerAsnMetGlyAlaMetGluAsnLysGlyLeuAsnIlePheAsnSer AAATTGGTGGCAATCCACAAACGGCACAGATGAAGATTCTGTCAATTGAAAGTGTGATTGCACAC
 - ▶ LysLeuValLeuAlaAsnProGlnThrAlaThrAspGluAspTyrLeuValIleGluSerValIleAlaHis

- 47 / 4 -

TABLE 5 (cont.)

GAATATTCCCATAACTGGACGGAAACCGTGTAAACCGCCGAGATGGTTCAACTAGGTTGAAGAAGGTTA
► GluTyrSerHisAsnTrpThrGlyAsnArgValThrArgArgAspGlyPheAsn
ACGGCTTCCGGGAACAAGATTTCTCAGATCAGTTCTCCGGGCCGAACCGATTAATAAGGGAAAATTTCCG

- 48 -

CLAIMS

1. An isolated DNA sequence selected from the group consisting of:
 - (i) an isolated DNA sequence comprising the nontypable *Haemophilus influenzae* serotype 1 LKP operon selected from the group consisting of:
 - a) SEQ ID NO: 4;
 - b) the complementary strand of SEQ ID NO: 4; and
 - c) DNA sequences that hybridize to SEQ ID NO: 4;
 - (ii) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipP* gene selected from the group consisting of:
 - a) nucleotides 1882 to 2532 of SEQ ID NO: 4;
 - b) the complementary strand of a); and
 - c) DNA sequences that hybridize to a);
 - (iii) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipC* gene selected from the group consisting of:
 - a) nucleotides 2854 to 3636 of SEQ ID NO: 4;
 - b) the complementary strand of a); and
 - c) DNA sequences that hybridize to a);
 - (iv) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipR* gene selected from the group consisting of:
 - a) nucleotides 4016 to 6238 of SEQ ID NO: 4;
 - b) the complementary strand of a); and
 - c) DNA sequences that hybridize to a);
 - (v) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipM* gene selected from the group consisting of:
 - a) nucleotides 6259 to 6873 of SEQ ID NO: 4;
 - b) the complementary strand of a); and

-49-

- c) DNA sequences that hybridize to a);
 - (vi) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP *hipA* gene selected from the group consisting of:
 - 5 a) nucleotides 6955 to 8365 of SEQ ID NO: 4;
 - b) the complementary strand of a); and
 - c) DNA sequences that hybridize to a); and
 - (vii) an isolated DNA sequence comprising the *Haemophilus influenzae* serotype 1 LKP tip adhesin comprising nucleotides 6955 to 8265 of SEQ ID NO: 4.
2. An isolated *Haemophilus influenzae* protein, selected from the group consisting of:
 - (a) a serotype 1 LKP pilin protein, having the amino acid sequence comprising SEQ ID NO: 5;
 - 15 (b) a serotype 1 LKP periplasmic chaperone protein having the amino acid sequence comprising SEQ ID NO: 6;
 - (c) a serotype 1 LKP membrane anchor protein having the amino acid sequence comprising SEQ ID NO: 7;
 - 20 (d) a serotype 1 LKP tip associated protein having the amino acid sequence comprising SEQ ID NO: 8;
 - (e) a serotype 1 LKP tip adhesin protein having the amino acid sequence comprising SEQ ID NO: 9; or
 - 25 (f) a serotype 5 LKP pilin protein having the amino acid sequence comprising SEQ ID NO: 3; or biologically active fragments thereof.
3. A recombinant *Haemophilus influenzae* LKP tip adhesin fusion protein comprising a biologically fragment of the LKP tip adhesin protein and maltose binding protein or glutathione-S-transferase.

-50-

4. A recombinant *Haemophilus influenzae* serotype 1 LKP tip adhesin fusion protein having the amino acid sequence comprising SEQ ID NO: 11, or a biologically active fragment thereof.
5. A method of producing an antibody which binds to *Haemophilus influenzae* LKP tip adhesin comprising immunizing a mammal with a recombinant *Haemophilus influenzae* LKP tip adhesin fusion protein.
6. A recombinant expression vector comprising a DNA insert encoding a *Haemophilus influenzae* LKP pilus, said expression vector capable of expressing a biologically active LKP pilus in a procaryotic or eucaryotic cell.
10
7. A procaryotic or eucaryotic host cell transformed with an expression vector comprising a DNA insert encoding a *Haemophilus influenzae* LKP pilus, said expression vector capable of expressing a biologically active LKP pilus in the host cell.
15
8. A method of producing *Haemophilus influenzae* serotype 10, serotype 11 or serotype 12 LKP pilus in a procaryotic or eucaryotic host cell comprising the steps of:
20
 - a) inserting a DNA sequence encoding a serotype 10, serotype 11 or serotype 12 LKP pilus into an expression vector capable of expressing a biologically active LKP pilus in the host cell, thereby producing a LKP pilus expression vector; and
25
 - b) transfecting an appropriate host cell with the expression vector produced in step a) and maintaining the transfected host cell under
30

-51-

conditions suitable for the expression of a LKP pilus in the host cell.

9. A DNA probe capable of hybridizing to a DNA sequence encoding the *Haemophilus influenzae* tip adhesin protein comprising nucleotides between about 6955 to 8265 of SEQ ID NO: 4.
5
10. A recombinant DNA molecule which encodes a *Haemophilus influenzae* tip adhesin protein or active fragment thereof.
- 10 11. A method of assaying for the presence of *Haemophilus influenzae* in a biological sample comprising the steps of contacting the sample with a DNA probe comprising about 400 nucleotides capable of hybridizing to a DNA sequence encoding a tip adhesin protein under conditions suitable for hybridization and detecting the presence of hybridized DNA.
15
12. A method of vaccinating a mammal against *Haemophilus influenzae* comprising administering to the mammal an effective amount of *Haemophilus influenzae* LKP tip adhesin protein, or a biologically active fragment thereof.
20
13. A method of protecting mammals against infections caused by *Haemophilus influenzae* comprising administering to the mammal an effective amount of a composition comprising *Haemophilus influenzae* LKP tip adhesin protein, or a biologically active fragment thereof, and a pharmaceutically acceptable carrier.
25

-52-

14. A vaccine composition for protecting mammals against infections caused by *Haemophilus influenzae* comprising a pharmaceutically acceptable carrier and *Haemophilus influenzae* LKP tip adhesin protein, or a biologically active fragment thereof.

5

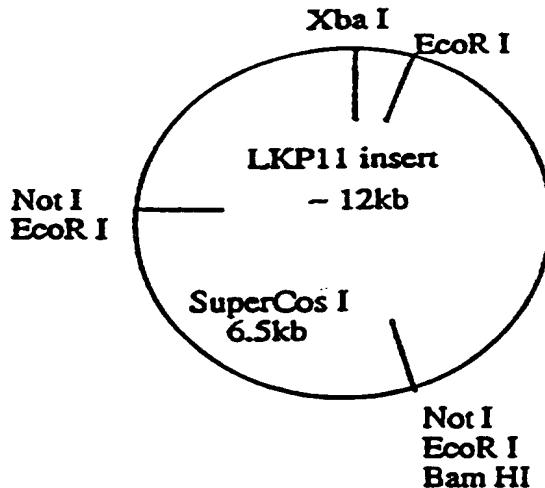
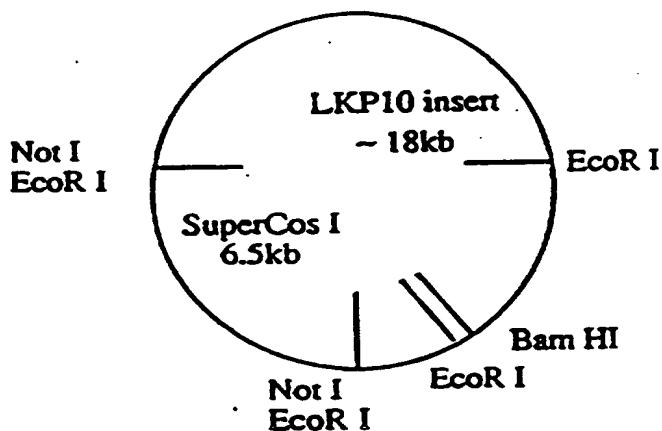
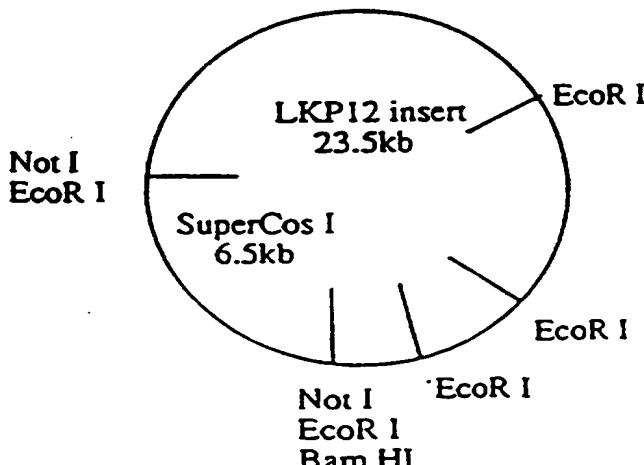
1/5

| | | | | | | | | | | | | | | | |
|-----------|--------------------|-------------|------------|------------|-------------|---------------|---------------|-------------|---|---|---|---|---|---|---|
| LKP1 hifa | MKKRTTGSLI | LLAFATNAAD | PQVSTETSGK | VTFGGKVVEN | TCKVKTD SKN | MSVVLNDVGK | NHLKTRKD TA | * | * | * | * | * | * | * | * |
| LKP4 hifa | 10 | 20 | 30 | 40 | 50 | 60 | 70 | | | | | | | | |
| LKP1 hifa |LL... |G.VQA | -DIN. | |EH.. |L... | | S.S...VN..> | | | | | | | |
| LKP4 hifa | 10 | 20 | 30 | 40 | 50 | 60 | 70 | | | | | | | | |
| LKP5 hifa |LL... |G.VQA | ADPNP..K.. | Y..... | SGNRD | A..SQ.GY..> | | | | | | | | | |
| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | | | | | | | | |
| LKP1 hifa | MPTPFTINLE | NCSTTTTNN | KPVATKVGY | FYSWKNADEN | NEYTLKNTKS | GNDAAQNWN | QTFDANGTDA | * | * | * | * | * | * | * | * |
| LKP4 hifa | 70 | 80 | 90 | 100 | 110 | 120 | 130 | | | | | | | | |
| LKP5 hifa |T.Q | ..DP..ANGT | ANK.N...L. |V.KE |NF... | EQT TA.Y.T... | ..LMES...K..> | | | | | | | | |
| | 80 | 90 | 100 | 110 | 120 | 130 | 140 | | | | | | | | |
| LKP1 hifa |T..G.NAN.G.-- | ..K.N...V. |N..KE | S....S.LT | .T.K.D... | I.QE..> | | | | | | | | | |
| | 150 | 160 | 170 | 180 | 190 | 200 | 210 | | | | | | | | |
| LKP1 hifa | IEVNGNTTD | FTHSNMTNDVA | TQQTVNHNHI | SGKATINGEN | NVKLHYIARY | YATAQAEAGK | VESSVDFQIA | * | * | * | * | * | * | * | * |
| LKP4 hifa | 140 | 150 | 160 | 170 | 180 | 190 | 200 | | | | | | | | |
| LKP5 hifa | 140 | 150 | 160 | 170 | 180 | 190 | 200 | | | | | | | | |
| | G.ADKTID. | ...K.NGSTN | SDKP-T... | SATAL.NQG | DIA....Q. | ...GM.S... | GPT...P..> | | | | | | | | |
| LKP1 hifa | YE* | | | | | | | | | | | | | | |
| LKP4 hifa | | | | | | | | | | | | | | | |
| LKP5 hifa | 210 | | | | | | | | | | | | | | |

SUBSTITUTE SHEET (RULE 26)

Figure 1

2/5

CLJ11**Fig. 2A****CLJ10****Fig. 2B****CLJ12****Fig. 2C**

3 / 5

KIEEGKLVIWINGDKGYNGLAEVGKKPEKDTGIKVTVEHPDKLEEKFPQVAATGDGPDIIF
WAHDRFGGYAQSGLLAEITPDKAHQDKLYPFTDAVRYNGKLIAYPLAVEALSLIYNKDLL
PNPPKTWEIIPALDKELAKGKSALMFNLQE PYFTWPLIAADGGYAFKYENGKYDKIKDVG
VDNAGAKAGLTFLVDLIKKNKHMNADTDYSIAEA AFNKGETAMTINGPWAWSNIDTSKVN
YGVTVLPTFKGQPSKPFVGVLISAGINAASPNKELAKEFLENYLLTDEGLEAVNKDKPLGA
VALKS YEEELAKDPRIAATMENAQKGEIMPNIPQMSAFWYAVRTAVINAASGRQTVD EALK
DAOQTRITKIEGRTLSSNPVWANIKTVOGTTSGFPLLTRTEFTENGLOWNVSA LO PAYIVSSO
ARDNLDTVHIOSSEINAPTNSLAPENNINTKSAVELGYSFAGITCTSNCPTMKLPLLFRP
OLTNLTTPPGKKNSDGGEIFKLNESNLGVSFQIGVKNTSLDWVNAAKNFSSLKVLMVPF
NSSKSIISLHLRAKEHLLTDSSLNNNDITIDPMNTSIGRINLETWRGSTGNFSVKYVGEDKG
DISIFFNTPKILKKOORRCTLNNA P VSPNPVKLR AVKKRELEAOSEMEGGTFOLRVNC DN
TTYNKAN

Fig. 3

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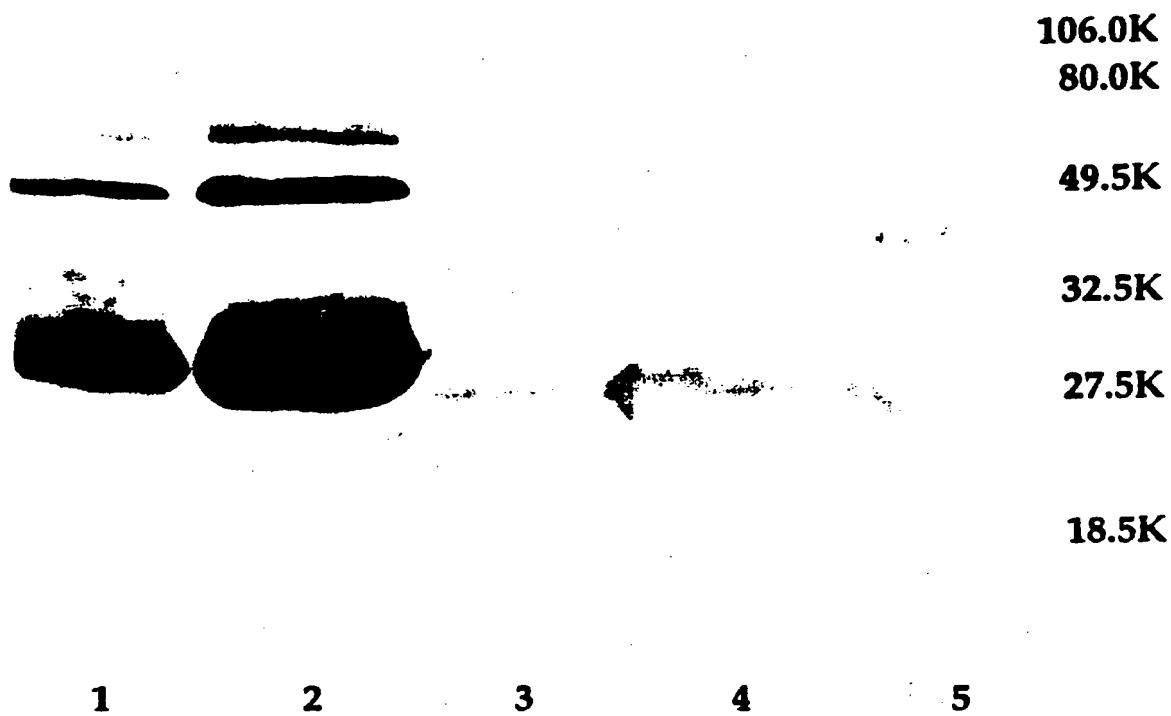


FIG. 4

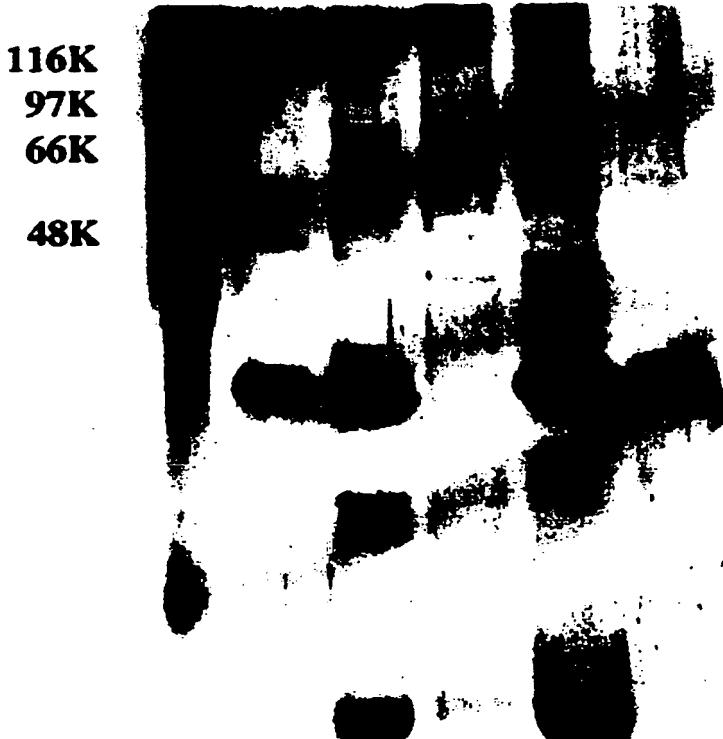
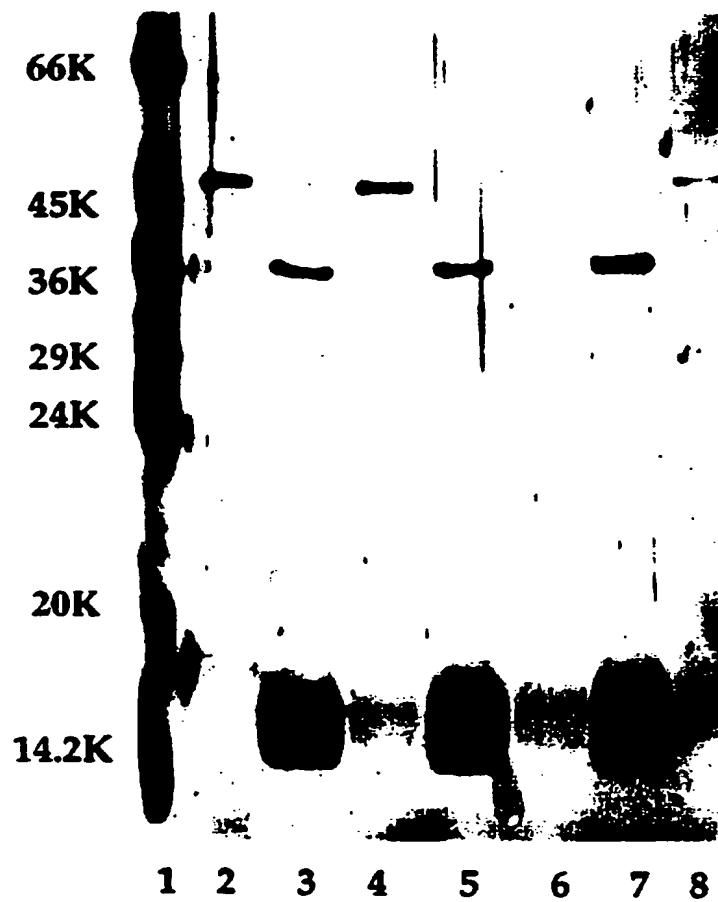
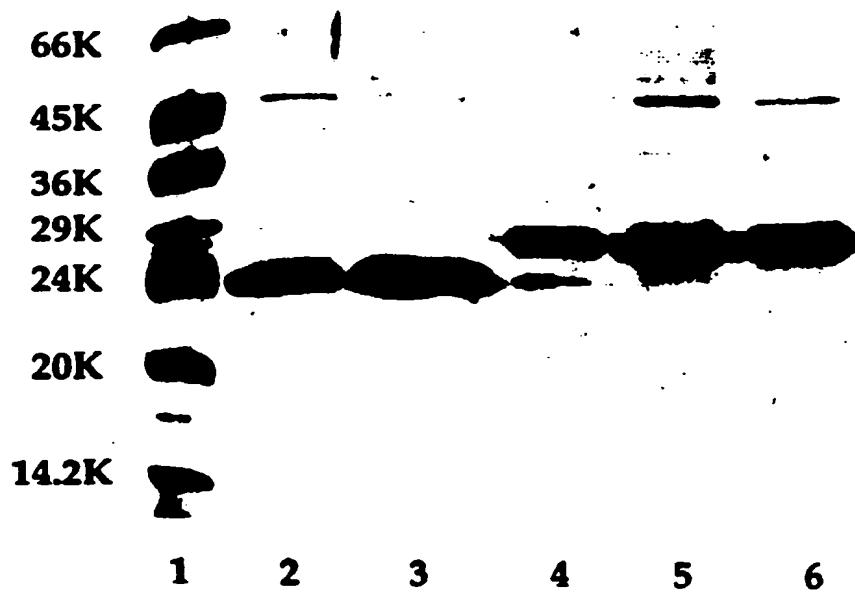


FIG. 5

1 2 3 4 5 6

5/5

FIG. 6**FIG. 7****SUBSTITUTE SHEET (RULE 26)**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 95/08789

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: C12N 15/31, C07K 14/285, A61K 39/102, C12N 1/21, C12N 5/10, C12Q 1/68
 According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: C12N, A61K, C07K, C12Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EDOC, MEDLINE, BIOSIS, DERWENT BIOTECHNOLOGY ABSTRACT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| X | WO, A1, 9319090 (BARENKAMP, STEPHEN, J.), 30 Sept 1993 (30.09.93), page 5, line 9 - line 36 -- | 1-11 |
| X | US, A, 5336490 (CHARLES C. BRINTON, JR. ET AL), 9 August 1994 (09.08.94), column 2, line 30 - line 63, claims | 1-8 |
| A | -- | 9-11 |
| X | Database EMBL/GenBank/DBJ on STRAND, ID=HIIFC, AC=U02932, Watson et al: "Identification of a Gene essential for Piliation in Haemophilus influenzae type b with Homology to the Pilus Assembly Platform Genes of Gram-Negative Bacteria", 1994. -- | 1-2 |

 Further documents are listed in the continuation of Box C. See patent family annex.

- * Special categories of cited documents:
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search

30 November 1995

Date of mailing of the international search report

11.01.96

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 95/08789

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| X | Database EMBL/GenBank/DDBJ on STRAND, ID=HIHIFB, AC=X66606, Smith AL et al: "hif B of <i>H. influenzae</i> is a member of the chaperone family", 1992. | 1-2 |
| | -- | |
| X | Database EMBL/GenBank/DDBJ on STRAND, ID=HIHIIFA, AC=X16991, van Ham SM et al: "Cloning and expression in <i>Escherichia coli</i> of <i>Haemophilus influenzae</i> fimbrial genes establishes adherence to oropharyn- geal epithelial cells", EMBO J., vol 8, p3535, 1989. | 1-12 |
| | -- | |
| P,X | Database EMBL/GenBank/DDBJ on STRAND, ID=HII9795, AC=U19795, Green BA et al: "Sequence of LKP serotype 5 hifA gene", 1995. | 1-2 |
| | -- ----- | |

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 95/08789

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: 12-14
because they relate to subject matter not required to be searched by this Authority, namely:
See PCT Rule 39.1(iv): Methods for treatment of the human or animal body by surgery or therapy, as well as diagnostic methods.
2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

114511

INTERNATIONAL SEARCH REPORT

Information on patent family members

30/10/95

International application No.

PCT/US 95/08789

| Patent document cited in search report | Publication date | Patent family member(s) | | Publication date |
|--|------------------|-------------------------|---------|------------------|
| WO-A1- 9319090 | 30/09/93 | AU-A- | 3916893 | 21/10/93 |
| | | EP-A- | 0632814 | 11/01/95 |
| | | FI-A,D- | 944273 | 15/11/94 |
| | | JP-T- | 7506248 | 13/07/95 |
| | | NO-A,D- | 943431 | 10/11/94 |
| ----- | ----- | ----- | ----- | ----- |
| US-A- 5336490 | 09/08/94 | AU-A- | 3772389 | 12/01/90 |
| | | WO-A- | 8912460 | 28/12/89 |



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